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FLOWERING AND POD SETTING IN GRAM, *CICER ARIETINUM*, L.[1]

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GRAM, *Cicer arietinum*, L., is an important staple pulse crop in India, occuping annually over 14,000,000 acres. In the Bombay Presidency, gram stands foremost among the pulses, occupying over 750,000 acres annually.

The improvement of this important crop was taken up in 1933 at the newly opened Cereal Breeding Station at Kundewadi, Niphad, Nasik District. Along with the plant breeding investigations agronomic and botanical studies were also undertaken. This paper presents observations on flowering and fruiting in gram.

REVIEW OF LITERATURE

Howard, *et al.* (2)[3] observed that flowers open from 9 a.m. and close the same day before sunset. As a rule they open again next morning between 8:30 and 11 a.m. and close finally late in the afternoon. The length of time a flower remained open varied from 7 to 15 hours. These workers further observed that the lowest buds open first and that flowering follows a cymose arrangement. The anthers dehisce and pollination occurs in the bud stage insuring self-fertilization. Cloudy or rainy conditions are deterimental to setting of pods.

Ayyar and Balsubrahmanyan (3) found a considerable amount of cleistogamous flowers in a summer crop. The incidence of cleistogamy is considered to vary according to nutritional conditions of the soil. They found that most of the flowers that opened on the first day, as a rule, did not open on the second day. In the normal crop active blooming was between 9 and 10 a.m., while the summer crop bloomed mostly at 2 p.m. The second opening was earlier in the day than the first one. Dehiscence and pollination occurred a day before the opening of the flower.

The observations of Shaw and Khan (4) show that the incidence of sterility and of two-seeded pods are closely associated with yield and that both vary with the season.

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[2]Crop Botanist to Government of Bombay and Graduate Assistants, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 557.

MATERIAL AND METHODS

Eighteen pure local types, the Local and an improved type, Nagpur-62, from the Central Provinces formed the material for the present studies.

Gram is usually sown by a three-coultered drill. In order to obtain uniform spacing and to facilitate observation, the seed was dibbled at a distance of 4 inches in rows 18 inches apart. Dibbling was done by a poker which made holes of uniform depth. Seed was deposited in the holes and covered with loose soil and pressed lightly.

In studying the relation of flowering and pod formation individual flowers were numbered and dated. Pods from each of these were harvested separately. In observing blooming, standards of flowers that had bloomed were clipped off slightly every day to distinguish them from fresh flowers. No detrimental effect of clipping of standards was observed. In all cases border plants were discarded.

RESULTS

FLOWERING

Flowering in individual plants.—In Table 1 is shown flowering of five individual plants of a typically early strain, G-693, and in Table 2 that of the five plants of a late strain, G-758. In each case the frequencies of the five plants have been added together and averages for each day are given.

It will be seen from Table 1 that in G-693 plants begin to flower as early as November 21, but that continuous blooming does not commence until a week later. At this time most of the branches have their buds fully developed so that the first flowers on most of the branches start simultaneous blooming. The tempo of blooming increases gradually and is in full swing for about two weeks, then a gradual decline sets in. The average maximum number of flowers per day in G-693 was 7.20, while an individual plant might have had as many as 10 flowers a day.

The flowering in G-758 (Table 2) commenced as early as November 23, but like the early strain G-693 it gained momentum after about a week. Plants continued flowering as late as December 26, 10 to 12 days later than G-693. The average number of maximum flowers was 4.60, while the highest number recorded was 11. On the whole, G-758 exhibited a lower amount of flowering than G-693.

Flowering in populations.—Twenty-five plants in 19 different pure types and in the Local were studied to ascertain the amount of flowering and pod formation. The data are summarized in Table 3.

It will be seen that the early types commenced blooming from 34 to 46 days after sowing and finished in from 67 to 70 days. In the mid-late types blooming commenced from 38 to 48 days after sowing and lasted from 27 to 37 days. The late and very late types did not differ much from the mid-late types.

Nagpur-62 was in a class by itself, commencing to flower very late and continuing for nearly a month and a half. It will be noted that the Local, although mid-late in maturity, showed as long a range as Nagpur-62.

There was evidently a good deal of variation in the total number of flowers per plant. It will be noted that, in general ,the early types possessed a minimum number of flowers per plant. The average number of flowers per plant was more or less the same in early, mid-late, and late types. The very late and extremely late strains showed much lower averages

TABLE 1.—*Blooming in five individual plants of the early strain G–693.*

Plant No.	November 1935									
	21	22	23	24	25	26	27	28	29	30
4	1	0	0	0	0	0	2	2	1	4
8	0	0	0	0	1	0	1	1	3	4
9	0	0	1	0	0	0	1	1	0	1
10	0	0	0	0	0	1	2	1	1	6
12	0	0	0	1	0	2	3	2	2	4
Total	1	0	1	1	1	3	9	7	7	19
Flowers per plant per day	0.2	0	0.2	0.2	0.2	0.6	1.8	1.4	1.4	3.8

	December 1935							
	1	2	3	4	5	6	7	8
4	5	4	4	4	4	5	5	5
8	5	6	6	9	6	8	5	4
9	1	1	2	5	2	3	4	1
10	6	4	7	8	6	4	7	2
12	5	1	3	3	3	4	6	3
Total	22	16	22	29	21	24	27	15
Flowers per plant per day	4.4	3.2	4.4	5.8	4.2	4.8	5.4	3.0

	December 1935							
	9	10	11	12	13	14	15	16
4	4	6	2	2	2	0	0	0
8	2	8	5	1	2	0	1	0
9	2	6	1	4	5	2	2	4
10	6	10	4	2	4	1	0	0
12	4	6	6	1	2	2	0	0
Total	18	36	18	10	15	5	3	4
Flowers per plant per day	3.6	7.2	3.6	2.0	3.0	1.0	0.6	0.8

Time of opening and closing.—During the season of 1934–35, opening and closing of flowers was observed in Nagpur-62 gram. On January 29, 1935, a number of buds were selected in the evening and observations recorded at hourly intervals the next day. The results are summarized in Table 4.

Of the 20 buds under observation, 11 opened on the first day and the remainder the next day. The opening of flowers on the first day was in the afternoon between 2:35 and 5:30. This was a cloudy day. All the buds closed between 6 and 6:30 p.m., immediately after sunset. These flowers re-opened on the second day (January 31, 1935) between 11:15 a.m. and 12:07 p.m. and remained fully opened until sunset, when all of them closed soon after. The interval between the first and second opening was from 18 to about 23 hours. Seven out of the 11 buds re-opened for the *third* time on February 1, 1935, between 10:15 and 10:46 a.m., the interval between the second and third opening being 22 to 23 hours.

TABLE 2.—*Blooming in five individual plants of the late strain G-758.*

Plant No.	November 1935							
	23	24	25	26	27	28	29	30
1	0	0	0	1	1	1	0	2
2	0	0	0	0	0	1	1	1
3	0	0	0	0	0	1	1	0
4	1	1	1	1	0	1	0	5
5	0	0	0	0	0	0	1	1
Total	1	1	1	2	1	4	3	9
Flowers per plant per day	0.2	0.2	0.2	0.4	0.2	0.8	0.6	1.8

Plant No.	December 1935									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	2	4	1	4	3	5	5
2	0	1	2	2	0	2	2	2	2	3
3	1	1	2	1	1	1	2	0	1	1
4	4	4	4	3	5	1	4	4	4	11
5	1	1	1	3	1	2	3	3	2	3
Total	7	9	11	11	11	7	15	12	14	23
Flowers per plant per day	1.4	1.8	2.2	2.2	2.2	1.4	3.0	2.4	2.8	4.6

Plant No.	December 1935							
	11	12	13	14	15	16	17	18
1	5	3	7	1	5	5	0	0
2	3	4	4	5	6	7	4	3
3	4	1	5	5	1	3	0	0
4	4	5	4	5	5	4	2	0
5	3	3	2	3	1	4	3	1
Total	19	16	22	19	18	23	9	4
Flowers per plant per day	3.8	3.2	4.4	3.8	3.6	4.6	1.8	0.8

Plant No.	December 1935							
	19	20	21	22	23	24	25	26
1	0	0	0	0	0	0	0	0
2	4	1	5	1	3	0	0	2
3	1	2	0	0	0	0	0	0
4	3	1	2	0	0	0	0	0
5	3	1	4	3	1	1	2	4
Total	11	5	11	4	4	1	2	6
Flowers per plant per day	2.2	1.0	2.2	0.8	0.8	0.2	0.4	1.2

The buds which opened for the first time on January 31 between 11:29 a.m. and 2:32 p.m. re-opened for the second time only. No third opening of these flowers was observed. January 31 was a clear day.

TABLE 3.—*Summary of flowering and pod setting in 20 different types of gram during 1935–36.*

Type No.	Life period in days	Period of flowering from sowing in days	Maximum and minimum number of flowers per plant	Average number of flowers per plant	Average number of pods per plant	Percentage pod setting
1	2	3	4	5	6	7
			Early Types			
G–258	95	46–70	32–94	65.6	36.4	55.5
G–262	100	34–70	21–84	58.0	30.7	52.9
G–397	100	36–70	23–89	64.6	36.4	56.3
G–693	100	35–67	31–126	68.2	37.7	55.2
G–769	100	43–68	25–125	71.6	39.1	54.6
G–306	100	39–69	31–95	53.4	24.6	46.1
Averages..				63.57	34.15	53.43
Local.....	103	36–80	25–123	68.7	32.2	46.8
			Mid-late Types			
G–248	103	44–76	20–116	67.0	35.5	53.0
G–412	103	45–80	8–97	62.9	33.9	53.9
G–421	103	38–75	33–100	65.8	34.4	52.2
G–494	103	46–75	5–125	68.6	37.9	55.2
G–705	103	48–75	11–144	77.4	41.4	53.5
Averages..				68.3	36.62	53.56
			Late Types			
G–130	107	39–78	17–111	75.7	29.4	38.8
G–339	107	48–75	50–150	87.1	44.1	50.6
G–531	107	42–73	15–187	87.2	36.6	41.9
G–758	107	43–80	19–90	61.0	27.4	44.9
G–434	107	41–74	23–79	46.0	22.1	48.0
Averages..				71.40	31.92	44.84
			Very Late Types			
G–348	110	51–79	6–75	47.4	27.2	57.3
G–WF3	110	46–80	13–97	49.0	24.5	50.0
Averages..				48.20	25.85	53.65
			Extremely Late Type			
Nagpur–62	130	52–95	10–86	42.4	23.3	54.9

It will be noticed that in the two sets of flowers those that opened on January 30 did so late in the afternoon, while the second lot flowered much earlier on January 31.

In order to observe blooming of flowers on a large scale a large number of unopened buds of G-262 were tagged in the season of 1935–36. The data are given in the Table 5.

All the 104 flowers that opened for the first time on November 27, 1935, closed that day after sunset. The next day all except 5 re-opened between 10 a.m. and 2 p.m., the bulk of the flowers opening in the

TABLE 4.—*Blooming of flowers in cloudy and clear weather during 1934–35.*

Bud No.	Cloudy day, Jan. 30, 1935, time of first opening	Partly cloudy day, Jan. 31, 1935		Interval between 1st and 2nd opening in hours	Clear day, Feb. 1, 1935		Interval between 2nd and 3rd opening in hours
		Time of first opening	Time of second opening		Time of second opening	Time of third opening	
1	—	12:03 p.m.	—	22:57	11:00 a.m.	—	—
2	5:30 p.m.	—	11:32 a.m.	18:02	—	10:46 a.m.	23:14
3	4:13 p.m.	—	12:04 p.m.	19:51	—	10:28 a.m.	22:24
4	5:22 p.m.	—	11:33 a.m.	18:11	—	—	—
5	—	2:32 p.m.	—	19:43	10:15 a.m.	—	—
6	2:35 p.m.	—	11:34 a.m.	20:59	—	10:15 a.m.	22:41
7	—	11:30 a.m.	—	22:45	10:15 a.m.	—	—
8	5:23 p.m.	—	12:05 p.m.	18:42	—	10:17 a.m.	22:12
9	—	11:29 a.m.	—	22:49	10:18 a.m.	—	—
10	3:03 p.m.	—	12:06 p.m.	21:03	—	—	—
11	—	12:06 p.m.	—	22:14	10:20 a.m.	—	—
12	—	12:30 p.m.	—	22:15	10:45 a.m.	—	—
13	4:41 p.m.	—	12:07 p.m.	19:26	—	—	—
14	—	11:35 a.m.	—	22:47	10:22 a.m.	—	—
15	5:11 p.m.	—	11:35 a.m.	18:24	—	10:23 a.m.	22:48
16	—	12:10 p.m.	—	22:53	11:03 a.m.	—	—
17	—	1:34 p.m.	—	22:00	11:34 a.m.	—	—
18	4:15 p.m.	—	11:25 a.m.	19:10	—	—	—
19	2:39 p.m.	—	11:20 a.m.	20:41	—	10:29 a.m.	23:09
20	4:10 p.m.	—	11:15 a.m.	19:05	—	10:27 a.m.	23:12

TABLE 5.—*Opening of flowers en masse in G-262 during 1935-36.*

Time	Nov. 27, 1935, No. of buds opening 1st time	Nov. 28, 1935		Nov. 29, 1935	
		No. of buds opening 2nd time	No. of buds closing	No. of buds opening 3rd time	No. of buds closing
9 a.m.	—	—	—	9	—
10 a.m.	—	12	—	2	—
11 a.m.	1	10	—	1	—
12 noon	22	63	—	2	—
1 p.m.	46	8	—	—	4
2 p.m.	10	6	—	—	2
3 p.m.	—	—	12	—	1
4 p.m.	6	—	2	—	4
5 p.m.	5	—	14	—	2
6 p.m.	14*	—	71	—	1
Total	104	99†	99	14	14

*Half open.
†Five buds did not open the second time.

forenoon. All these closed from 3 p.m. to 6 p.m. on the same day, the majority closing at 6 p.m. On the third day 14 flowers re-opened for the third time. These were the 14 buds which had half opened on the first day.

Sequence of opening of flowers.—Each branch, whether tertiary or secondary, forms an entity and blooms independently of other branches. Flowering, therefore, goes on simultaneously in various branches and sub-branches. The basal flowers bloom first, followed by others in a cymose arrangement. The actual flowering is diagramatically illustrated in Fig. 1.

Cleistogamy.—No cleistogamous flowers were observed.

POD FORMATION

Amount of pod formation.—The incidence of pod setting was determined from averages obtained from the study of 25 plants in each type. The average number of flowers and pods per plant and the percentage of setting are given in the last three columns of Table 3.

The percentage of setting varied in early strains from 46.1 to 56.3 with a general average of 53.43. Although mid-late types showed a slightly higher average number of flowers per plant than the early types, the average setting of pods was about the same as in the earlier strains. The late types generally had a higher number of flowers per plant than the early and mid-late strains, but the pods formed per plant were fewer, resulting in lower setting. The very late types had a very low average number of flowers and pods. The setting, however, was as high as the early types. The Nagpur-62 strain showed the same behavior. The Local gram showed considerable low setting, although the average number of flowers per plant was the same as that of mid-late strains.

Although early types were somewhat lower in average number of flowers per plant than the late strains, the higher amount of setting

of the former made them considerably higher yielding. In order to ascertain this feature further correlation coefficients were calculated between the amount of flowering and pod setting and are given in Table 6.

TABLE 6.—*Correlation between number of flowers and number of pods in early and late strains of gram.*

Early strains	n	r	Late strains	n	r
G-258........	25	0.9158	G-130	24	0.7979
G-262........	25	0.8455	G-339.......	24	0.8134
G-397.........	25	0.8080	G-531........	25	0.8605
G-693.........	25	0.9539	G-758........	24	0.7845
G-769.........	24	0.9589	G-434........	25	0.8923
G-306.........	25	0.8829	———	—	———
Average r....	131	0.9070	Average r...	107	0.8338

The theoretical values of correlation coefficients at 0.01 point for n-2 = 22 and 23 are 0.515 and 0.505. It will be seen that all the values are highly significant. The coefficients of early strains as a rule are larger than those of late strains. The estimated average values of r in the two groups are 0.9070 and 0.8338, respectively, the former being significantly larger.

Sterility.—A certain number of pods in a gram plant are without seed. Such pods are confined, usually, at the extremity of the branches (Fig. 1). Any flowers formed above the empty pods are shed, as a rule, Thus empty pods result from late-formed flowers. The incidence of sterility in early types varied during the two years, 1934–35 and 1935–36 from 5.3 to 12.5% in early and from 2.6 to 16.8% in late types. The incidence of sterility therefore is very variable from season to season.

Number of seeds in a pod.—The number of seeds per pod in the various strains was noted in 1934–35 and 1935–36. One-seeded pods formed the largest proportion, ranging from nearly 66 to 87%. In 1934–35 the proportion of two-seeded pods was much higher than in the following year. Three-seeded pods rarely occurred. There was considerable variation in the proportion of one- and two-seeded pods from season to season.

The two-seeded pods were usually located at the base of the branch, i.e., the first or the second flower at the base of the branch usually resulted in two-seeded pods (Fig. 1). In case the lower pods were damaged by insects the pods immediately above them usually developed two seeds. In the beginning a plant has few pods to nourish, hence, it is likely to develop both the ovules in a pod. This is probably the most likely reason of the location of two-seeded pods at the base of the branches.

Weight of seed in one- and two-seeded pods.—The combined weight of seeds in the two-seeded pods was more than the seed from one-seeded pods. Individually, however, the grains in the two-seeded pods weighed less than those from the one-seeded pods. One of the grains in the two-seeded pods was invariably heavier than its companion. In two-seeded pods the grains were adpressed and conse-

quently developed an irregular shape unlike the grains in one-seeded pods, which were round and well developed.

In a plant of strain G-693 the weights of seeds from one-seeded pods ranged from 0.102 to 0.163 gram, as compared with 0.105 to 0.130 gram of larger seeds from two-seeded pods.

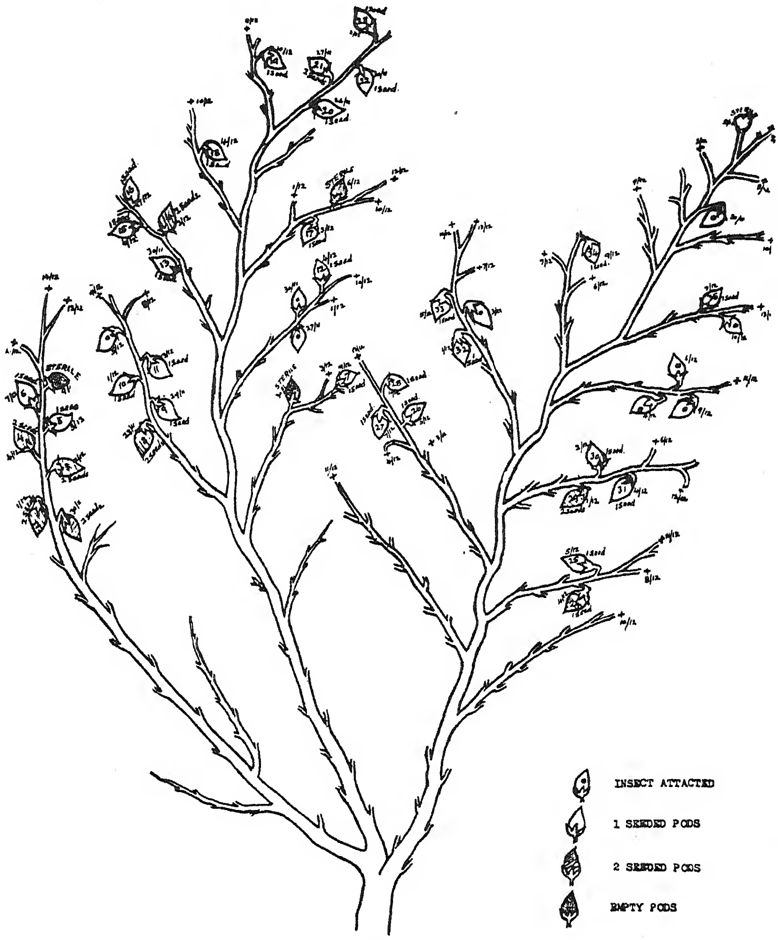

FIG. 1.—Graphic illustration of a gram plant showing dates of flowering, pod formation, and number of seeds per pod.

DISCUSSION

The period of daily blooming is longer at Niphad than at Pusa and Coimbatore as observed by the Howards and Khan (2) and by Ayyar and Balasubrahmanyan (3), respectively. The closing of flowers is also delayed at Niphad as compared to the time of closing at the other two places. The variations may either be due to inherent differences

in the material or to the climatic conditions obtaining at the various places. It is more likely that both factors may be operating.

In addition to the two successive openings of a flower as observed by the above workers, we also observed blooming for the third time. Such cases were associated with young buds which had not completely opened on the first day and in flowers whose initial opening was delayed until late in the afternoon due to cloudy weather. About 5% of the flowers opened only once. In this respect our observations are in accord with those of the Howards but differ from those of Ayyar and Balasubrahmanyan who recorded 78 to 85% such cases at Coimbatore. We did not observe any cleistogamous flowers, which occurrred in abundance at Coimbatore.

In early types more flowers manage to develop into pods than in the late types. The correlation coefficients between the amount of flowering and pod setting of early types were generally higher than those of late strains, the average value of r of the former being significantly larger than that of the late strains. Since there is not much difference in number of flowers, amount of sterility, and two-seeded pods, it appears that late types shed more flowers than early types. We have observed that late-formed flowers are usually shed, and since flowering of late strains continues a week or more beyond that of the early types, it follows that more shedding of flowers must be taking place in the late strains, with consequent reduction in pods.

The excessive shedding of flowers in late types appears to be related to soil moisture. The non-irrigated gram crop has to grow throughout its life period on the available soil moisture which progressively diminishes as the season advances. It has been observed that most of the earlier-formed flowers result in pods, while late-formed flowers have a considerably lower percentage of setting. Evidently, after a certain limit, the soil moisture begins to act as a limiting factor and its influence is greater on late strains whose flowering period parallels the lower moisture conditions of the soil.

Shaw and Khan (4) mention that pink-flowered types show larger percentages of two-seeded pods, suggesting a probable association of the two characters. The lowest amount of two-seeded pods in such types as mentioned by them was 31% and the highest 72%. In our material the strains under consideration were all pink flowered and none showed more than 29% of two-seeded pods.

SUMMARY

1. The average number of flowers blooming per day in an early type of gram was 7.20, while on an individual plant as many as 9 to 10 flowers may bloom on a day.

2. Blooming in a strain population continues from 3 to 5 weeks. The range of flowering is more or less the same in strains of different maturity periods. Early types begin to flower a week earlier than late ones.

3. Under Niphad conditions early, mid-late, and late types have more or less the same average number of flowers per plant, but the very late types have much smaller averages.

4. In clear weather flowers begin to bloom from about 11 a.m. to 2 p.m. Cloudy weather retards blooming. The second opening on the following day is earlier than the first. Flowers whose first opening is dealyed and very young buds which bloom partly the first time late in the afternoon, usually show a third opening. Flowers close soon after sunset.

5. Blooming in a branch or in a sub-branch is independent of other branches. Basal flowers are first to bloom, followed by others in a cymose arrangement.

6. No cleistogamous flowers occur under Niphad conditions.

7. Early strains set relatively more pods than late types, and are thus higher yielding.

8. A certain amount of sterility is due to empty pods which are usually located at the end of the branches. The number of such pods varies from season to season.

9. Under Niphad conditions most of the pods are one-seeded. The incidence of one- and two-seeded pods fluctuates greatly according to the season. Three-seeded pods are rare.

10. The two-seeded pods are located, as a rule, at the base of the branches. The seeds in such pods are irregular and one of them is invariably heavier than its companion.

LITERATURE CITED

1. Fisher, R. A., Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 5, 1934.
2. Howard, A., Howard, G. L. C., and Khan, A. R. Some varieties of Indian gram (*Cicer arietinum* L.). Mem. Dept. Agr. India, Bot. Ser., 7: 213–235. 1915.
3. Ayyar, V. Ramanatha, and Balasubrahmanyan, R. Anthesis and pollination in Bengal gram (*Cicer arietinum*). Madras Agr. Jour., 23: 170–178. 1935.
4. Shaw, F. J. F., and Khan, R. A. Studies in Indian pulses; II. Some varieties of Indian gram (*Cicer arietinum* L.). Mem. Dept. Agr. India, Bot. Ser., 19: 27–47. 1931.

INHERITANCE OF GROWTH CURVE[1]

KOICHI EBIKO[2]

AMONG the genetic studies with regard to plant growth, the inheritance of common quantitative characters at a certain period of growth, such as height of plants, number of culms, or weight of plants, has already been worked out by many investigators, but very little is known about the growth curve which presents the entire course of development of plants from emergence to maturity.

The investigations described in this paper were undertaken with the purpose of determining whether the course of development of plants is inherited by analyzing the growth curves of parents and their progeny.

ROBERTSON'S GROWTH EQUATION

Approaching the growth problem from the chemical point of view, Robertson proposed a formula expressing the course of an autocatalytic, monomolecular reaction in his growth equation.

Already, a number of investigators (3, 4, 9)[3] have recognized that Robertson's growth equation is well fitted to the growth phase of various plants and animals; and also, in regard to the cereal crops, the possibility of making use of the equation has been accepted by Gaines and Nevens (4), Iwamoto (5), and Uyeda (10).

Attempts were made in the present investigation to make use of Robertson's growth equation. As given by Robertson (8) in its simple form, that is upon integration, this equation is expressed by the formula

$$\text{Log}\ \frac{x}{A-x} = K\ (t - t_1),$$

where x is the amount of growth which has been attained in time t, A is the maximum degree of growth attained in the growth cycle, K is a constant which is determined from a known value of x at a given time t, and t_1 is the time at which growth is half completed, that is when $x = \frac{1}{2}$ A.

In this equation, the developmental course of plants is indicated by the constant K, the magnitude of which determines the general slope of the growth curve.

Fig. 1, made after Gains and Nevens (4), shows three diagrammatic slopes of growth curves which are represented by three different values of K. From these curves it may be seen that the increase of slopes is accompanied by the increase of values of K.

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[1]Contribution from the Department of Agronomy, Agricultural Experiment Station of the South Manchuria Railway Company, Koshurei, Manchuria. Also published in Japanese in the Scientific Papers dedicated to Dr. M. Akemine for the commemoration of the thirtieth anniversary of his professorship in the Hokkaido Imperial University, Japan, 1938. Received for publication March 12, 1938.

[2]Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 562.

MATERIALS AND METHODS

Spring wheat was used as the material in these studies. A cross was made between the early-ripening variety, Italian Spring, and the late-ripening variety, Sapporo Harukomugi No. 10, which appeared to the writer to possess some remarkably different habits of growth.

The growth curve of plants may be presented either on the basis of successive weights of the entire plant or on the basis of successive heights.

The author believes that the former method is more accurate for expressing the growth process in plants; but when such curves are to be constructed on the weight basis, different plants have to be used at each weighing and the data can

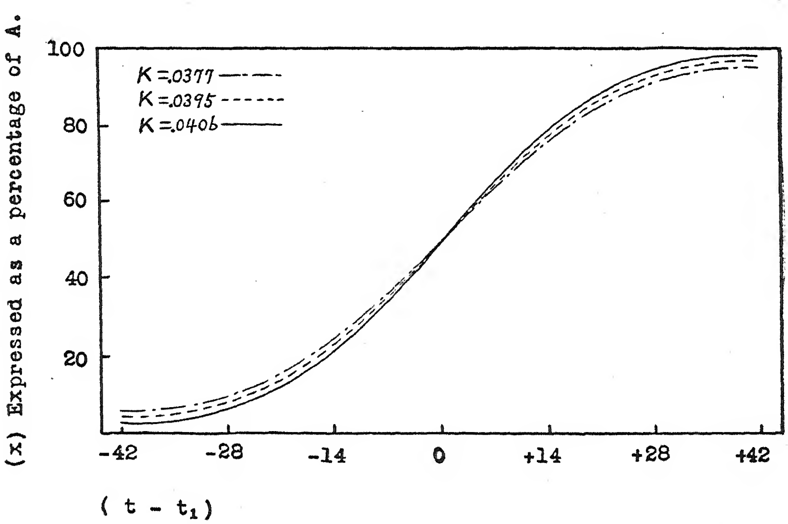

Fig. 1.—Showing form of the curve to Robertson's equation Log $\frac{x}{A-x}=K(t-t_1)$ for three values of K, *viz.*, 0.0377, 0.0395, and 0.0406. (After Gaines and Nevens.)

not be obtained from the same plants. On the contrary, the height data can be obtained from the same plants, and also the investigator is enabled to work with a larger number of plants than would be possible by any other method because of the small amount of time required to make the necessary measurements. For these reasons the height method was employed in this investigation.

The hybrid seeds were space-planted 10 cm apart in rows 60 cm apart without any fertilizers in an uniform field and at the same time seeds of parents were also sown in the same manner as controls.

The height of plants was measured at weekly intervals from 43 days after sowing in 1935 and from 41 days after sowing in 1936.

During the vegetative phases of growth measurements were made from the ground to the tallest leaves. After heading, when the top of the heads became higher than the tallest leaves, the measurements were made to the top of the heads.

At the calculation of constant K in Robertson's equation, by inserting the observed and calculated values of A, t_1, t, and x in the equation, a series of values of K was obtained corresponding to the different times t for the same plant.

The average of the several values thus obtained was taken as the value of K of the growth equation for each plant.

INHERITANCE OF CONSTANT K

As has been already stated, the magnitude of K determines the slope of the growth curve, hence it is necessary to examine the distribution of constant K in cross studies in order to ascertain whether the growth curve is inherited.

The results obtained on the F_1 plants and parents of the cross Italian Spring × Sapporo Harukomugi No. 10, grown in 1935, are are presented in Table 1.

From Table 1 it will be observed that the values of K of F_1 plants showed intermediate distribution between the ranges of K in both parents, and especially that the same average value, 0.0395, was obtained in reciprocal crosses.

This relationship is presented diagrammatically in Fig. 1, showing that the constant K may be controlled by Mendelian rule.

Data in Table 2 are the results obtained from F_2 and F_3 progeny grown in 1936.

Inspection of Table 2 shows that the frequency distributions of K of four F_3 families were considerably different and that, accordingly, their average values were not the same.

From these F_3 results it will be recognized that Mendelian segregation occurred in the F_3 population, and that, consequently, each family presented its own independent phenotype which must be controlled by some Mendelian factors. What factors are involved in the production of K is the next question.

As is shown in the frequency distribution of F_2 in Table 2, transgressive segregation for values of K occurred in the F_2 population. This indicates that there was transgressive inheritance with respect to the values of K, that is, that multiple factors were involved in the control of values of K.

From the above discussion, it can be emphasized that the constant K is inherited according to Mendelian rule, while, on the other hand, it is also necessary to keep in mind that K may at the same time be greatly affected by environmental conditions, from the fact that the differences between the values given in Table 1 (1935) and in Table 2 (1936) were noticeably great and also that a wide dispersion of frequency distribution of K was obtained in both 1935 and 1936.

SUMMARY AND CONCLUSIONS

There have not been reported, so far as is known to the writer, any studies on inheritance of the growth curve which expresses the entire course of development of plants, except by Ashby (1, 2). According to his investigations, the logarithmetic growth curve of F_1 which was obtained from corn plants during the vegetative period of growth, that is, from emergence to 70 days afterwards, was quite the same as the curve obtained from one of the parents, indicating that complete dominance occurred in this case.

TABLE 1.—*Frequency distribution for K values of the parents and F_1 progeny of the Italian Spring × Sapporo Harukomugi No. 10 wheat cross grown at Konuma, South Saghalien, in 1935.*

Parents and F_1 progeny	Number of plants for K value of																			Total	Average
	.030	.031	.032	.033	.034	.035	.036	.037	.038	.039	.040	.041	.042	.043	.044	.045	.046	.047	.048		
Sapporo Harukomugi No. 10	2	1	1	2	1	3	4	5	12	9	5	2	2	2	1					52	0.0377
Sapporo Harukomugi No. 10 × Italian Spring					1	1	5	2	5	5	4	9	5	2	2					41	0.0395
Italian Spring × Sapporo Harukomugi No. 10					1	1	2		4	2	8	6	3	1						28	0.0395
Italian Spring		1	1			1	1	3	5	5	3	6	8	4	2	2	2	1	1	46	0.0406

TABLE 2.—*Frequency distribution for K values of the parents and F_2 wheat cross, grown at Kinuma,*

Parents and progeny	Number of plants for K value of																	
	.031	.032	.033	.034	.035	.036	.037	.038	.039	.040	.041	.042	.043	.044	.045	.046	.047	.048
Sapporo Harukomugi No. 10	—	—	—	—	—	—	—	2	1	3	4	3	4	6	7	3	9	14
Italian Spring	—	—	—	—	—	—	—	—	—	—	—	1	—	5	3	4	5	6
F_2 progeny	1	1	1	6	4	7	7	6	27	31	39	45	62	67	76	82	57	65
F_3 progeny strain No. 12	—	—	—	—	1	—	1	1	—	3	2	4	4	6	4	5	8	5
F_3 No. 23	—	—	1	—	—	1	—	1	—	5	4	4	2	4	2	4	6	5
F_3 No. 65	—	—	—	—	—	—	1	—	1	—	1	—	4	2	5	5	6	10
F_3 No. 89	—	—	—	—	—	—	—	—	—	—	1	—	2	—	1	1	1	2

In the present study, by using wheat plants, attempts were made to determine whether the growth curve produced by the employment of Robertson's growth equation is inherited. In Robertson's growth equation, the constant K is of special significance for the investigation of inheritance of growth curve because the slopes of growth curves are affected by variations in the magnitudes of the constant K.

Since it has been pointed out by Copeman (3), Klages (6), and Iwamoto (5) that the values of constant K are greatly affected by environmental factors, all plants of parents and progeny were cultivated under as nearly uniform conditions as it was possible to obtain. Under these circumstances, the values of K were calculated from the data obtained from weekly height measurements.

According to the results thus obtained, the values of K in F_1 hybrids were intermediate between those of the parents and the same average values were obtained in F_1 reciprocal crosses. Furthermore, in F_3 progeny, such results were obtained that the frequency distribution of K of each family was considerably different, showing that each family presented its own independent phenotype.

From these F_1 and F_3 results, the author arrived at the conclusion that the constant K may be inherited according to the Mendelian rule.

If this is so, the next question is, What factors are involved in the production of constant K? In reply to this question, the writer wishes to state that multiple factors may be involved in the control of values of K in view of the results of F_2 in which frequency distribution was transgressively segregated.

LITERATURE CITED

1. ASHBY, E. Studies in the inheritance of physiological characters. I. A physiological investigation of the nature of hybrid vigour in maize. Ann. Bot., 44:457–468. 1930.
2. ———. Studies in the inheritance of physiological characters: II. Further experiments upon the basis of hybrid vigour and upon the inheritance of efficiency index and respiration rate in maize. Ann. Bot., 46:1007–1032. 1932.

and F_3 progeny of the Italian Spring×Sapporo Harukomugi No. 10 South Saghalien, in 1936.

Number of plants for K value of																				To-tal	Aver-age
.049	.050	.051	.052	.053	.054	.055	.056	.057	.058	.059	.060	.061	.062	.063	.064	.065	.066	.067	.068		
12	7	8	7	7	5	8	2	5	4	—	1	1	—	—	—	—	—	—	—	123	0.0492
7	7	9	7	12	9	6	5	3	3	—	2	2	1	—	—	—	1	1	—	99	0.0519
65	63	62	44	34	26	19	20	6	14	7	11	1	7	2	2	1	—	—	1	969	0.0473
11	6	11	7	9	7	9	2	3	4	2	—	—	3	2	—	1	—	—	—	121	0.0501
7	4	3	3	2	4	5	—	1	1	—	—	—	—	—	—	—	—	—	—	69	0.0473
7	10	7	8	8	2	7	1	3	3	1	1	1	2	1	1	—	—	—	—	98	0.0506
2	3	3	4	2	2	4	5	2	—	—	—	—	—	—	—	—	—	—	—	35	0.0514

3. COPEMAN, R. Autocatalysis and growth. Ann. Appl. Biol., 15:613–622. 1928.
4. GAINES, W. L., and NEVENS, W. B. Growth-equation constants in crop studies. Jour. Agr. Res., 31:973–985. 1925.
5. IWAMOTO, T. Growth of the wheat plant in Southern Saghalien. Saghalien. Central Exp. Sta. Tech. Bul. 13. 1935. (In Japanese.)
6. KLAGES, K. H. W. The value and application of growth curves to field plat experiments. Jour. Amer. Soc. Agron., 25:453–464. 1933.
7. POPE, M. N. The growth curve in barley. Jour. Agr. Res., 44:323–341. 1932.
8. ROBERTSON, T. B. On the normal rate of growth of an individual and its biochemical significance. Arch. Entw-Mech. Organismen, 25:581–614. 1908.
9. ———. The Chemical Basis of Growth and Senescence. Philadelphia and London. 1923.
10. UYEDA, S. On the growth curve of rice plants in transplanted fields. Proc. Crop Sci. Soc. Japan, 2:161–170. 1930. (In Japanese.) Abs. in Biol. Abs., 7:1828. 1933.

TIME OF CUTTING TIMOTHY: EFFECT ON THE PROPORTION OF LEAF BLADES, LEAF SHEATHS, STEMS, AND HEADS AND ON THEIR CRUDE PROTEIN, ETHER EXTRACT, AND CRUDE FIBER CONTENTS[1]

W. H. Hosterman and W. L. Hall[2]

THE proportion and chemical composition of the morphological parts found in the portion harvested for hay of the various leguminous hay plants when cut at different stages of maturity have been determined by a number of investigators. As a result of these studies the percentage of leaves has been used as an important factor in appraising the quality and feed value of legume hays. Similar detailed studies have never been made of the grasses used for hay. This paper presents some preliminary studies with reference to the proportion of leaf blades, leaf sheaths, stems, and heads of timothy harvested at different stages of maturity and their respective crude protein, ether extract, and crude fiber contents.

A review of the literature showed that a number of the agricultural experiment stations had collected data on the relation between time of cutting and yield of timothy *hay* per acre. Waters[3] reported, in addition to the yields, the composition of timothy hay cut at different stages of maturity. Trowbridge, *et al.*,[4] reported on the yields and composition of the heads, stalks with attached leaves, stubble, and bulbs for timothy cut at different stages of maturity. The stalks with attached leaf sheaths and leaf blades were not studied individually by these investigators, although they cited a need for such information.

PROCEDURE

During the summer of 1936 samples of ordinary timothy were collected at the Timothy Breeding Station, Bureau of Plant Industry, U. S. Dept. of Agriculture, Wooster, Ohio, for use in a percentage distribution and composition study of the various vegetative parts of the timothy plant that are utilized in the production of hay.

The several samples were cut during progressive stages of maturity and cured in the shade under such conditions that little, if any, of the plant parts were lost during drying. The five progressive stages of maturity were as follows: Nearly fully headed, early bloom, just past full bloom, about 10% of the heads straw colored, and heads mature. At Wooster during the season of 1936 these stages of

[1]Contribution from the Hay, Feed, and Seed Division, Bureau of Agricultural Economics, U. S. Dept. of Agriculture. Received for publication April 2, 1938.

[2]Marketing Specialist and formerly Associate Feed Technologist, now Chemist, Food and Drug Administration, respectively. The authors wish to acknowledge the assistance received from Morgan W. Evans, Division of Forage Crops and Diseases, Bureau of Plant Industry, who harvested the material used in this study.

[3]WATERS, H. J. Studies of the timothy plant, Part I. Mo. Agr. Exp. Sta. Res. Bul. 19.

[4]TROWBRIDGE, P. F., *et al.*, Studies of the timothy plant, Part II. Mo. Agr. Exp. Sta. Res. Bul. 20.

maturity were reached on the following dates: June 13, June 19, July 1, July 15, and July 28, respectively.

The dried samples were shipped to Washington for color measurements, separation into plant parts, and chemical analyses. Color measurements were made upon the unseparated cured plants from each cutting by the method developed and prescribed for use in measuring color under the official hay standards promulgated by the Bureau of Agricultural Economics, U. S. Dept. of Agriculture. The different timothy samples were then carefully separated by hand picking into leaf blades, leaf sheaths, stems, and heads, after which they were ground separately in a rotating knife type mill until all the material had passed through the 1-mm hole size screen.

Crude protein, ether extract, and crude fiber values were determined for each of the separations by the use of methods of analysis prescribed by the Association of Official Agricultural Chemists. From the percentage determinations of the various plant parts and the corresponding crude protein, ether extract, and crude fiber determinations for those parts the total percentage of crude protein, ether extract, and crude fiber in the hay obtained at each of the five stages of maturity was calculated. Corrections for variations in moisture were made by drying the material at 100° ± 3° C. in an electrically heated air oven for 18 hours.

RESULTS AND DISCUSSION

The separation analyses (Table 1) show that the weights of the leaf blades when compared with total plant weights decreased progressively from 38.2% for the early cut nearly full headed timothy to 10.0% for very late cut fully matured timothy. It is interesting to

TABLE 1.—*Total weight and color of timothy hay cut at different stages of maturity and the weight and percentage of total for leaf blades, leaf sheaths, stems, and heads.**

Date and stage harvested	Total weight, grams	Color		Leaf blades	
		Hue	% green†	Grams	%
June 13, nearly fully headed	500	10.45Y	100+	191	38.2
June 19, early bloom	528	10.00Y	100+	155	29.3
July 1, just past full bloom	658	9.13Y	100+	135	20.5
July 15, 10% heads straw colored	706	7.62Y	100+	81	11.5
July 23, heads mature	1,090	4.51Y	45	108	10.0

Date and stage harvested	Leaf sheaths		Stems		Heads	
	Grams	%	Grams	%	Grams	%
June 13, nearly fully headed	116	23.2	133	26.6	60	12.0
June 19, early bloom	105	19.9	174	33.0	94	17.8
July 1, just past full bloom	103	15.7	310	47.1	110	16.7
July 15, 10% heads straw colored	91	12.9	323	45.7	211	29.9
July 23, heads mature	122	11.2	422	38.7	437	40.1

*Calculated to an air-dry basis.

†For the purposes of interpreting hue readings in terms of percentage green color for timothy in the United States hay standards, a hue reading of 7.40Y is considered equivalent to 100% green color for field-cured hay. These samples were shade-cured and therefore have relatively high hue readings because shade-cured hay retains the green color to a greater extent than field-cured hay.

note that little decrease took place after the stage when 10% of the heads were straw colored. The relative weights of the leaf sheaths also decreased progressively although not as rapidly as the leaf blades. The relative weights of the stems increased from 26.6% for the nearly fully headed timothy to a maximum of 47.1% at full bloom and then decreased to 38.7% at the fully matured stage. The relative weights of heads increased from 12.0% to 40% with the greatest increase occurring after the plants had passed beyond the full bloom stage.

The calculated totals for crude protein, either extract, and crude fiber (Table 2) for the whole hay indicated a reduction in the crude protein content and an increase in the crude fiber content with very little change in the ether extract as the plant became more mature. However, when the plants were fully mature the large quantity of seed, which would naturally analyze high in crude protein and low in crude fiber, resulted in lowering the crude fiber content to the lowest of any stage of cutting and in increasing the crude protein content to approximately 8.0% which was almost as high as in the early stages of maturity.

The crude protein, ether extract, and crude fiber content of the various parts (Table 2) of the timothy plant indicated that the leaf blades were much higher in crude protein and ether extract and lower in crude fiber than the stems at all stages of maturity, while the leaf sheaths were intermediate between the leaf blades and stems. The crude protein content of the heads showed very little variation with increasing maturity except for the last sample, while the crude fiber content was about one-half as great when the heads were mature as it was in the early stages of maturity at which the timothy was cut.

The importance of this study as it relates to the production of high quality timothy hay is the interesting relationships which were shown between the crude protein, ether extract, and crude fiber in the various parts of the plant and the calculated totals for crude protein, ether extract, and crude fiber in the whole plant. Timothy cut prior to full bloom had 70% (Fig. 1) or more of the total protein of the hay in the leaf blades, leaf sheaths, and stems of the plant. Timothy hay which was allowed to stand until 10% of the heads were straw colored had at least 50% of the crude protein in the heads and that allowed to stand until fully mature had 70% of the crude protein in the heads. Since the higher crude protein content of the heads was due to the accompanying seeds, it is doubtful if timothy heads are of much value in field-cured hay because many of the heads might be shattered in the curing and storage operations and those seeds that are eaten are probably imperfectly digested.

The ether extract values indicated that the leaf blades contained over 50% of the ether extract when timothy was cut before the early bloom stage and that after the full bloom stage the ether extract in the heads increased rather rapidly.

The crude fiber values indicated that the stems contained 40% of the total crude fiber when the timothy was cut in the early bloom stage and 60% when allowed to stand until 10% of the heads of timothy were straw colored.

TABLE 2.—*Percentage of crude protein, ether extract, and crude fiber in timothy hay cut at different stages of maturity and the distribution of those constituents in the leaf blades, leaf sheaths, stems, and heads.**

Stage of maturity	Separation in relation to total weights, %	Chemical analysis			Relation to total		
		Protein, %	Ether extract, %	Fiber %	Protein, %	Ether extract, %	Fiber, %
		Whole Hay†					
Nearly fully headed	—	8.39	2.68	29.7	—	—	—
Early bloom	—	8.35	2.56	33.1	—	—	—
Just past full bloom	—	6.80	2.24	34.5	—	—	—
10% heads straw colored	—	6.99	2.53	33.5	—	—	—
Heads mature	—	7.94	2.67	28.7	—	—	—
		Leaf Blades					
Nearly fully headed	38.2	11.6	4.78	24.3	52.8	68.3	31.3
Early bloom	29.3	11.6	4.65	25.1	40.7	53.1	22.4
Just past full bloom	20.5	11.0	5.07	25.0	33.1	46.4	14.8
10% heads straw colored	11.5	9.04	5.35	25.0	14.9	24.5	8.7
Heads mature	10.0	6.60	5.35	25.9	8.31	20.2	8.0
		Leaf Sheaths					
Nearly fully headed	23.2	5.39	1.41	34.1	14.9	12.3	26.6
Early bloom	19.9	5.71	1.87	36.0	13.6	14.5	21.7
Just past full bloom	15.7	6.24	1.99	35.6	14.4	13.8	16.2
10% heads straw colored	12.9	7.42	2.68	35.8	13.7	13.8	13.7
Heads mature	11.2	6.08	3.05	35.3	8.56	12.7	13.9
		Stems					
Nearly fully headed	26.6	4.41	0.86	33.8	13.9	8.6	30.3
Early bloom	33.0	4.82	0.76	39.7	19.0	9.8	39.6
Just past full bloom	47.1	3.24	0.78	40.7	22.5	16.5	55.4
10% heads straw colored	45.7	2.94	1.07	43.0	19.2	19.4	58.5
Heads mature	38.7	2.76	1.28	41.6	13.5	18.7	55.7
		Heads					
Nearly fully headed	12.0	12.8	2.41	29.7	18.4	10.8	12.3
Early bloom	17.8	12.5	3.26	30.7	26.6	22.7	16.6
Just past full bloom	16.7	12.2	3.14	28.0	30.0	23.2	13.6
10% heads straw colored	29.9	12.2	3.59	21.5	52.2	42.3	19.1
Heads mature	40.1	13.8	3.22	15.6	69.6	48.3	21.9

*Calculated to an oven-dry basis. The average loss of weight on drying was 8.3%. None of the various parts analysed varied from this average by more than 0.5%.

†The total percentages of protein, ether extract, and fiber given for the whole hay are calculated from the percentages for the constituent parts given in this table.

In the United States standards for alfalfa hay, leafiness has been used as a grading factor because data from various sources showed that the crude protein content of the leaves averaged about 2½ times the crude protein content of the stems. The leaves and stems of alfalfa cut at the earlier stages of maturity were higher in crude protein than the leaves and stems of alfalfa cut at the full bloom to seed stage,

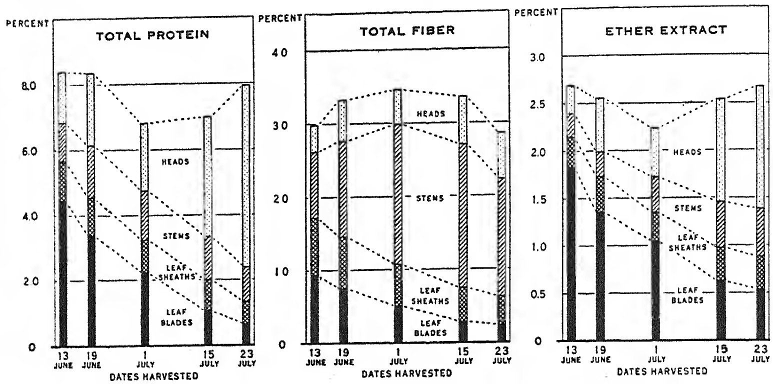

FIG. 1.—Relation of crude protein, crude fiber, and ether extract in the leaf blades, leaf sheaths, stems, and heads to the total crude protein, crude fiber, and ether extract in timothy hay at various dates of harvesting.

but there was no material change in the relation between the two. The early cut hay also had a higher percentage of leaves at time of cutting which materially influences the total protein found in the hay. Under these conditions the quantity of leaves present in the hay reflects the approximate protein content and, therefore, gives one a measure of feed value. As mentioned earlier in this paper, no data on the relation between leaf blades, leaf sheaths, stems, and heads of the grasses have heretofore been available. The results of this investigation indicate that the percentage of leaf blades and heads should be considered in determining the quality and feed value of timothy and perhaps other grass hays since the protein in the leaf blades decreased with maturity while the protein in the heads increased.

This type of study should be made with various strains of timothy selected for different percentages of leaf and stem, with those produced on different soil types, and under varying climatic conditions before definite conclusions can be drawn as to the full relationships of crude protein and crude fiber in the several morphological parts of the timothy plant. The results from the study described here will serve as a contribution to a knowledge of this subject. Similar studies should also be conducted with other grasses which are used for hay.

SUDAN GRASS MANAGEMENT FOR CONTROL OF CYANIDE POISONING[1]

F. T. Boyd, O. S. Aamodt, G. Bohstedt, and E. Truog[2]

UNDER certain conditions in Wisconsin, Sudan grass is one of the most satisfactory pasture grasses for midsummer. Its chief drawback, however, has been the possibility of poisoning of livestock by the cyanide or prussic acid which it may contain. The present investigation was undertaken for the purpose of determining the factors which give rise to a high poison content of Sudan grass in order that a program of management might be formulated which would eliminate or minimize the danger of poisoning.

OCCURRENCE AND FORMATION OF CYANIDE IN PLANTS

Since free or soluble cyanide is strongly toxic to plants, it seems reasonable to conclude that the accumulation of a considerable concentration of this poison in living plant tissue can only take place through the formation of an insoluble and non-toxic compound of the cyanide. In cyanogenetic plants, this compound may be one of several glucosides. In Sudan grass and sorghums, this glucoside is said to be *dhurrin*, which, on hydrolysis in the presence of the enzyme emulsion, yields glucose, parahydroxybenzaldehyde, and hydrocyanic acid. A very small portion of the cyanide may exist in living plant tissue in the free or non-glucosidic form.

No attempt is made in this paper to give more than a few of the many references pertaining to the subject in hand. The reader wishing further references is referred to a recent paper by Leeman (4)[3] which gives a rather complete discussion and an extensive bibliography relative to "Hydrocyanic Acid in Grasses." According to some of the theories reviewed and discussed by Leeman, cyanide is formed in certain plants due to a peculiar type of protein synthesis in which the nitrogen absorbed as nitrates from the soil by cyanogenetic plants, is changed to the form of hydrocyanic acid as an intermediate stage between nitrates and amino acids in the formation of proteins.

As rapidly as hydrocyanic acid is formed, it combines with glucose and benzaldehyde to form a non-toxic glucoside, which, in turn, does not accumulate if conditions are favorable for the rapid and complete synthesis of proteins. Since nitrogen is an essential constituent of HCN, it is probable that toxic quantities of cyanophoric compounds would not accumulate in nitrogen-starved plants. If the plant is not furnished with an adequate supply of available phosphorus, the for-

[1]Joint contribution from the Departments of Soils, Agronomy, and Animal Husbandry, University of Wisconsin, Madison, Wis. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station.

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[3]Figures in parenthesis refer to "Literature Cited", p. 582.

mation of certain proteins is inhibited and the accumulation of cyanophoric compounds may be accentuated.

EFFECT OF CYANIDE ON ANIMALS

The various species of animals react differently when fed plants containing cyanophoric glucosides. These differences are caused by different anatomical structures and different detoxifying abilities of various animals. Cattle and sheep are ruminants and both are known to be subject to poisoning by cyanophoric glucosides. The paunch or rumen of these animals is neither strongly acid nor alkaline in reaction, contains a large flora of micro-organisms, and considerable quantities of the enzyme emulsion. An excellent medium is thus provided for the hydrolysis of the glucoside with the liberation of the toxic agent—hydrocyanic acid. Horses and hogs, being non-ruminants, have only one stomach which is strongly acid in reaction due to the presence of HCl. This HCl reacts with the liberated HCN to form much less toxic substances as follows: $HCN + HCl + 2H_2O$

$$\longrightarrow HC{\overset{=O}{\underset{\diagdown OH}{}}} + NH_4Cl$$

Formic acid.

The toxifying action of HCN is almost immediate, that is, as soon as it is liberated from the glucosides. In a discussion of the toxicology of hydrocyanic acid, Hadley and Kozelka (3) state that the specific action of HCN on animals is that it inhibits the oxygen-activating enzyme, indophenol oxidase. When this happens, the release of energy through oxidation decreases, and if this goes far enough sickness and death result. The symptoms of this sickness are increase in rate and depth of respiration, increased pulse rate, no response to stimuli, and spasmodic muscular movements. Experimentally, it has been shown by various investigators that it takes a dose of about 1 gram of HCN to kill a cow of 1,000 pounds in weight. The amount may vary some depending on the detoxifying capacity and physical resistance of the animal.

Calculating on the basis of work done by Loevenhart, *et al.*, and by Turner and Hulpien, quoted by Hadley and Kozelka (3), it is found that dogs and rabbits can detoxify at the rate of approximately 0.5 mgm HCN per hour per pound of body weight without any toxic effects. Thus, on this basis, a 1,000-pound cow should be able to detoxify at the rate of about 0.5 gram of HCN per hour. It is therefore possible for cattle to consume forage containing small amounts of cyanide without ill effects or symptoms of cyanide poisoning. It is only when the poison enters the blood stream at a greater rate than the detoxifying rate of the animal that fatal poisoning follows.

EFFECT OF VARIOUS FACTORS ON CYANIDE CONTENT OF SUDAN GRASS

The factors influencing the amount of cyanide in plants have not been definitely determined and many conflicting theories regarding the matter have appeared in literature.

Manges (5) of Kansas in 1935 stated as follows: "Hydrocyanic acid is not found in appreciable quantities in healthy growing plants. The acid develops only when the normal growth of the plant has been retarded or stopped by drought, frost, bruising, trampling, wilting, mowing, and other causes. . . . . . The mature plant contains a smaller percentage of potential acid than the young plant, and plants grown on fertilized soil, especially soils which have been fertilized with nitrates, contain less than those grown on poor soil. . . . . . Immediately after the first frost in autumn there may develop a heavier concentration of acid than is normally present in the plants."

Rogers and Boyd (8) of Minnesota state that the pasturing by sheep and cattle of frozen Sudan grass containing relatively large amounts of hydrocyanic acid (according to picrate test tube test) did not result in sickness. They believed hydrocyanic acid to be most abundant in rapidly growing plant tissues, and claimed that Sudan grass which was badly stunted by drought contained less cyanide than plants growing under more favorable conditions.

Maxwell (6) in 1903 found HCN to be highest in sorghum in the early stages of growth, and that the amount of poison thus formed is governed largely by the nature of the soil, being higher when the soil is rich in the nitrogenous constituents of plant food.

Willaman and West (11) concluded that climate and variety of sorghum may be more important factors than supply of available soil nitrogen in determining the content of cyanide in sorghum tissue. Later, Willaman (12) stated that plants which are in an unhealthy condition due to malnutrition, insect injury, improper transpiration, or inadequate moisture supply are usually higher in content of cyanide than healthy ones.

Swanson (10) found the most hydrocyanic acid in Sudan grass when the plants were young and in a vigorous condition. He also (9) reported that freezing of Sudan grass did not cause a decrease in the cyanide content found if the test is made before the plants thaw and wilt. After thawing and wilting the cyanide content dropped rapidly.

Moody and Ramsey (7) concluded that sorghum-Sudan grass hybrids are especially high in poison and dangerous to pasture.

Acharya (1) has suggested the ensiling of sorghum as a means of destroying the poison principle. His results with sorghum support those of the present investigation as regards the influence of stage of growth, time of day, and drying on the cyanide content.

DETERMINATION OF CYANIDE IN PLANT TISSUE

In order to make possible a thorough study of the factors involved in the poisoning of livestock by Sudan grass, it was found desirable to investigate the methods which have been proposed for the determination of cyanide in plant tissue. As a result of this investigation by Boyd and Truog, a very satisfactory method for this purpose has been evolved.[4]

In this method, 8 grams of chopped plant tissue are placed in a Kjeldahl flask along with 300 cc of water and 5 cc of chloroform. The contents of the flask are then subjected to steam distillation causing the liberated HCN to distill. After passing through a condenser, the HCN is caught in an alkaline solution. Five cc of this distillate are then treated in a test tube or other suitable vessel with 5

[4]It is proposed to publish the details of the method elsewhere.

cc of an alkaline picrate solution, causing, on heating in a water bath, the development of a red color whose intensity is proportional to the amount of cyanide present. This color is then compared with proper standards, and thus the amount of cyanide involved is determined. The method is relatively simple and expeditious, and is believed to be considerably more reliable than some of the other methods which have been proposed. Its use proved invaluable in the studies that followed.

SOIL FERTILITY AS A FACTOR INFLUENCING THE AMOUNT OF CYANIDE IN SUDAN GRASS

On a single occasion in July, 1936, 17 cows in a herd of 35 died while pasturing on short, stunted Sudan grass near Argyle, Wisconsin. Samples of the short stunted Sudan grass were collected from this field and analyzed and found to contain 346 mgm HCN per 100 grams of dry tissue. Sorghum-Sudan hybrids were not found in this field. The soil was acid and deficient in available phosphorus but contained 50 pounds of nitrate nitrogen per acre. Under greenhouse culture, Sudan grass grown on the same soil when young contained twice as much cyanide as plants in a similar stage grown on soil of medium fertility, and eight times as much cyanide as plants, also in a similar stage, grown on a soil of high and well-balanced fertility. These findings suggested further studies of the effect of fertilizer treatments on the cyanide content of Sudan grass and sorghum.

INFLUENCE OF NITROGEN FERTILIZATION ON CYANIDE CONTENT

The addition of nitrogen fertilizers to soils deficient in nitrogen increased the cyanide content of Sudan grass and sorghum grown on these soils. Similar treatment of soils well supplied with nitrogen had little effect on the cyanide content of the plants produced. It was found that stunted plants, when chlorotic due to a nitrogen deficiency, contained very little cyanide.

The effect of heavy applications of nitrogen fertilizers in pot tests on the cyanide content of Sudan grass at different stages of growth is given graphically in Fig. 1. These results indicate conclusively that Sudan grass in both the fertilized and unfertilized pots was highest in cyanide content at the earliest stages of growth. The Sudan grass which received nitrogen fertilizer was consistently higher in cyanide than the unfertilized grass, but was below the toxic limit after it had reached a height of 1 foot.

Some sorghum plants, grown in pots, became quite chlorotic due to lack of nitrogen when about 8 inches in height. These plants had a low cyanide content. A different nitrogen fertilizer was added to each of three of these pots. A fourth was left unfertilized. The fertilized plants changed rapidly from yellow to dark green in color and increased in cyanide content. Alway and Trumbull (2) have reported similar findings. The results, presented in Fig. 2, reveal marked increases of cyanide content due to the addition of the three nitrogen fertilizers, urea, potassium nitrate, and ammonium sulfate. The slight differences obtained with the three fertilizers in increase of cyanide content are probably due more to various experimental errors, such

as those involved in sampling, than in actual differences in the effect of the three nitrogen fertilizers.

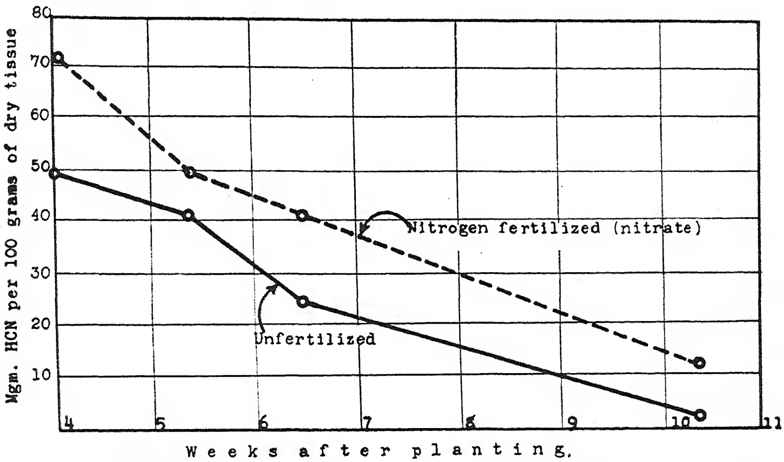

FIG. 1.—Cyanide content of nitrogen-fertilized and unfertilized Sudan grass at different stages of growth (pot test).

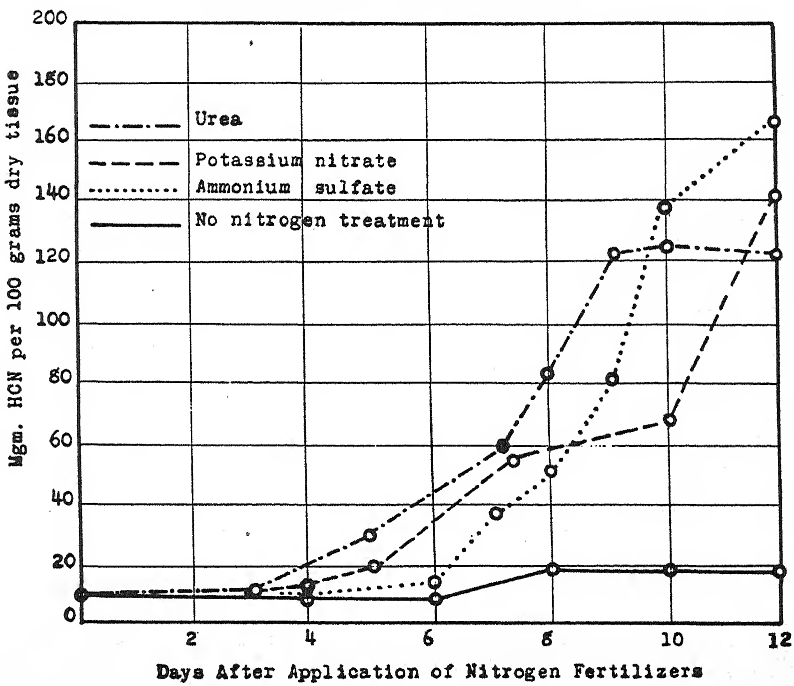

FIG. 2.—The cyanide content of sorghum after fertilization with various nitrogen fertilizers. Plants were grown in pots and fertilized when 8 inches high.

INFLUENCE OF PHOSPHATE FERTILIZATION ON CYANIDE CONTENT

When adequate amounts of phosphate fertilizer were applied to phosphorus-deficient soils, Sudan grass planted thereon grew rapidly, and six weeks after planting only small amounts of cyanide were found in the Sudan grass. On the other hand, high concentrations of cyanide were found in plants of the same age grown on soils deficient in phosphorus. Since phosphorus is an important constituent of the nucleo-proteins, which are an essential constituent of all cells, an adequate supply of phosphorus is needed if rapid cell division and plant growth are to take place. An adequate supply of avialable phosphorus thus tends to decrease the cyanide content in two ways: First, it makes possible and speeds up the formation of certain proteins which use up nitrogen that might otherwise accumulate in the form of cyanide. Second, by speeding up cell division, plants more rapidly reach the stage of lower cyanide content. Sudan grass grown in greenhouse beds on a soil very deficient in available phosphorus but well supplied with other plant nutrients, contained 127.0 mgm HCN per 100 grams of dry matter 30 days after the date of planting. Sudan grass grown in similar beds which received complete fertilizer treatment was found to contain only 36.3 mgm HCN at the same date. Sorghum plants grown in sand cultures without phosphate fertilization contained 427.2 mgm HCN per 100 grams of dry tissue six weeks after planting, while sorghum plants similarly grown with complete fertilizer treatment contained only 25.3 mgm at the same age.

INFLUENCE OF POTASH FERTILIZATION ON CYANIDE CONTENT

The addition of potash fertilizers to pots containing soil in which Sudan grass and sorghum were grown, produced little, if any, effect on the cyanide content of either Sudan grass or sorghum. These greenhouse results were verified with field experiments. None of the soils in which these plants were grown was especially low in available potash. For that reason a stunted growth due to potash deficiency did not develop in the untreated areas and the influence of a really low level of available potash was not determined.

STAGE OF GROWTH AS A FACTOR INFLUENCING THE CYANIDE CONTENT OF SUDAN GRASS

The results of greenhouse tests conducted during March and April, 1937 and presented in Fig. 1, show that the cyanide content of Sudan grass is highest in the earlier stages of growth. Later in the season, samples of Sudan grass from fields were collected to check this matter. On August 3 on the Fred Techam farm, Middleton, Wis., 10 cows broke into a quarter-acre paddock of second growth Sudan grass which had reached a height of about 4 inches and was dark green in color. Eight cows died within a half-hour after entering the paddock. Samples of grass and soil were taken from this paddock to the laboratory for analysis. The soil was found to be well supplied with available

phosphorus (100 to 125 pounds per acre) and available potash (250 to 325 pounds per acre), and contained 25 to 35 pounds of nitrate nitrogen per acre. This green, second growth Sudan grass contained 126.5 mgm HCN per 100 grams dry matter. In this case, the early stage of growth was the factor responsible for the high content of cyanide.

The results given in Fig. 3 were obtained from second growth Sudan grass grown on the farm of A. J. Glover, Fort Atkinson, Wis. These results were obtained in connection with an interesting experi-

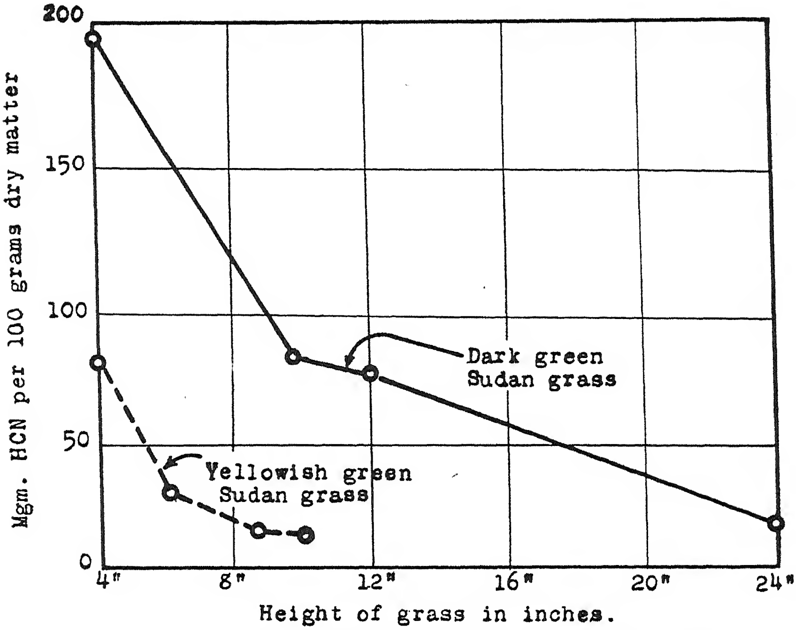

FIG. 3.—Relation between height and cyanide content of dark green and yellowish green second growth Sudan grass on A. G. Glover farm. Samples were taken at weekly intervals.

ment. Mr. Glover harvested a hay crop consisting of a mixture of Sudan grass and soybeans grown on a relatively fertile lowland field. The second growth of Sudan grass was dark green in color. When about 5 inches in height several samples were collected and tested for cyanide content. All of the samples had a high cyanide content. A heifer was allowed to graze some of this Sudan grass which was about five inches in height. After eating for about 10 minutes, the heifer began to stagger and refused to eat any more of the Sudan grass. A veterinarian was present and stated that the heifer showed symptoms of cyanide poisoning. Two days later, six cows were turned into this field of short Sudan grass. Three of the cows were thin and in poor physical condition, while the other three were in good condition. Two of the emaciated cows, after eating for 15 minutes, laid down and showed marked symptoms of acute cyanide poisoning. It was neces-

sary to administer an intravenous injection of sodium thiosulfate to revive these two cows and prevent death. Later, after this Sudan grass had reached a height of about 18 inches, tests showed that the cyanide content had gone down to a low level. Mr. Glover then pastured the grass without any ill effects to his cattle.

INFLUENCE OF VARIETY AND SPECIES OF SUDAN GRASS ON CYANIDE CONTENT

Sorghums are often much higher in cyanide content than Sudan grass. Eight strains of Sudan grass were grown in the greenhouse and analyses of the plant tissue produced showed differences between strains in cyanide content. Only one out of seven selected inbred strains was found to contain appreciably less cyanide than the commercial strain used in these experiments. All strains examined were found to be high in cyanide at the very young stage in both first and second growths, but the height at which the plant reached the non-toxic condition varied considerably. Some of the data are presented in Table 1.

TABLE 1.—*A comparison of the cyanide content of several strains of Sudan grass at approximately 12 inches in height.*

Strain	Mgm HCN per 100 grams dry tissue
T_{13}	12.00
T_{14}	28.40
O_{22}	37.72
O_3	49.72
T_{10}	88.04
T_{12}	32.52
Nebraska strain	65.88
Commercial strain	30.00

From these data it appears that the strain T_{13} is the only strain whose cyanide content was significantly lower than the commercial strain. When T_{13} was tested at a much earlier stage of growth, it was found to be relatively high in cyanide content but lower than some of the others. Two weeks after the above tests were made, both the commercial strain and T_{13} were equally low in cyanide.

EFFECT OF ENSILING ON CYANIDE CONTENT OF SUDAN GRASS

An experiment was conducted to determine the effect of ensiling on the cyanide content of Sudan grass. It was believed that the fermentation processes which take place when grass is ensiled would decompose the toxic cyanide and form non-toxic organic acids.

Three milk bottles were tightly packed with Sudan grass high in cyanide content and closed with a stopper having a valve attachment which would allow the escape of gases but prevent any gases entering from the atmosphere. In bottle No. 1, the grass was treated with molasses; in bottle No. 2, with a mixture of HCl and H_2SO_4 similar to the well-known A.I.V. method; while in bottle No. 3 was given no additional treatment. The Sudan grass placed in the bottles came from the same lot of grass which was high in cyanide content (94.5 mgm

per 100 grams dry tissue). After six weeks of fermentation, the bottles were opened and the grass tested. It was found that no significant loss of cyanide took place in either the molasses-treated grass or the untreated grass. A slight decrease in cyanide content was observed, however, in the acid-treated Sudan grass of bottle No. 2. As a result of this experiment it is concluded that if Sudan grass is poisonous at the time of ensiling, it will, at least under some conditions, remain toxic after ensiling for several weeks. It is to be noted that Acharya (1) reports a greatly reduced cyanide content of sorghum after ensiling for two months.

EFFECT OF FROST ON CYANIDE CONTENT OF SUDAN GRASS

Contrary to the opinions of some (5), no increase in the cyanide content was found when Sudan grass was frosted. Several farmers' samples of frosted plants were received and analyzed. None of these samples was found to be high in poison, though none of the grass represented by these samples was short and poisonous at the time of freezing. The Sudan grass in some field experimental plants was dark green in color and about 2 feet in height at the time of the first frost. Samples of this grass were collected and tested for cyanide before and after the first frost. The cyanide content was low in both cases and no higher after the frost than before the frost. Cattle were allowed to graze some of this Sudan grass after a killing frost, but symptoms of cyanide poisoning did not develop. These observations indicate that freezing does not materially increase the cyanide content of Sudan grass. If favorable weather for growth follows a killing frost, the Sudan grass will send forth new shoots and leaves which are apt to be very high in cyanide, and if pastured, cause cyanide poisoning. When this happens, it is of course natural to infer that it is the frosted grass that caused the poisoning rather than the new growth.

INFLUENCE OF DROUGHT ON CYANIDE CONTENT OF SUDAN GRASS

The belief that drought is one of the chief factors involved when Sudan grass becomes poisonous has been supported by some investigators (4, 11). The writers subjected some Sudan grass about a foot in height and low in cyanide content growing in the greenhouse and also in the field, to drought. In neither case did an increase in cyanide content take place. However, when, due to drought, water is withheld from short, dark green Sudan grass, a high cyanide content may persist, because the grass is unable to grow out of the high cyanide stage. Thus drought probably operates as a factor largely by keeping the plants small, in which stage they are generally higher in cyanide content than when larger. Drought keeps the plants small by withholding water and probably by lessening much more the availability of phosphates to plants than that of nitrogen.

EFFECT OF DRYING ON CYANIDE CONTENT OF SUDAN GRASS

It has been held by some (5, 9) that cyanogenetic plants lose their toxic properties by drying or being made into hay. The results obtained by analyzing plants grown in the greenhouse and dried in various ways are presented in Table 2. These results show that air drying did not lower the cyanide content. Plants that were high in poison at the time of cutting did not lose appreciable quantities of cyanide due to air drying or sun curing. When the plants were oven-dried at a temperature of 115° C, however, there resulted a very significant decrease in the content of cyanide. Several samples of Sudan grass hay which were tested for farmers contained only traces of the poison. None of these samples represented grass less than 1 foot in height at the time of cutting. Thus, if the grass is low in cyanide content at the time of cutting, hay made from this grass will also be low in content of cyanide; however, if small green plants with a high cyanide content are made into hay, the hay will probably, if carefully cured and stored, have a high cyanide content.

TABLE 2.—*Effect of sun curing and air and oven drying on the cyanide content of sorghum and Sudan grass.*

Sample	Cyanide content in mgm HCN per 100 grams dry tissue			
	Fresh tissue	Air dried	Oven dried	Sun cured
		Sorghum		
Entire plant	193.6	204.0	27.6	—
Leaves only	372.4	370.7	97.0	350.5
		Sudan grass		
1	59.5	61.3	—	53.1
2	47.6	47.6	—	—
3	60.4	58.4	—	—

DIURNAL VARIATION IN CYANIDE CONTENT

Greenhouse experiments were conducted to determine the diurnal variation in the cyanide content of Sudan grass and sorghum. Samples were taken for analysis at 8:00 a.m., 1:00 p.m., and 7:00 p.m. The results obtained for Sudan grass harvested at 1:00 p.m. were about 30% higher than those obtained for grass harvested in the morning or evening. In the case of sorghum, the cyanide content at 1:00 p.m. was also considerably higher than in the morning and evening. It is to be noted that these results accord with those reported by Acharya (1). In grazing practice, these differences are probably of little significance except in borderline cases.

The data obtained from this experiment were subjected to statistical analysis. The differences between the cyanide content at noon, morning, and evening were found to be significant. The percentage error found ranged between 7 and 9%, depending on the mean of the cyanide contents of the plants tested. Some of the data are given graphically in Fig. 4.

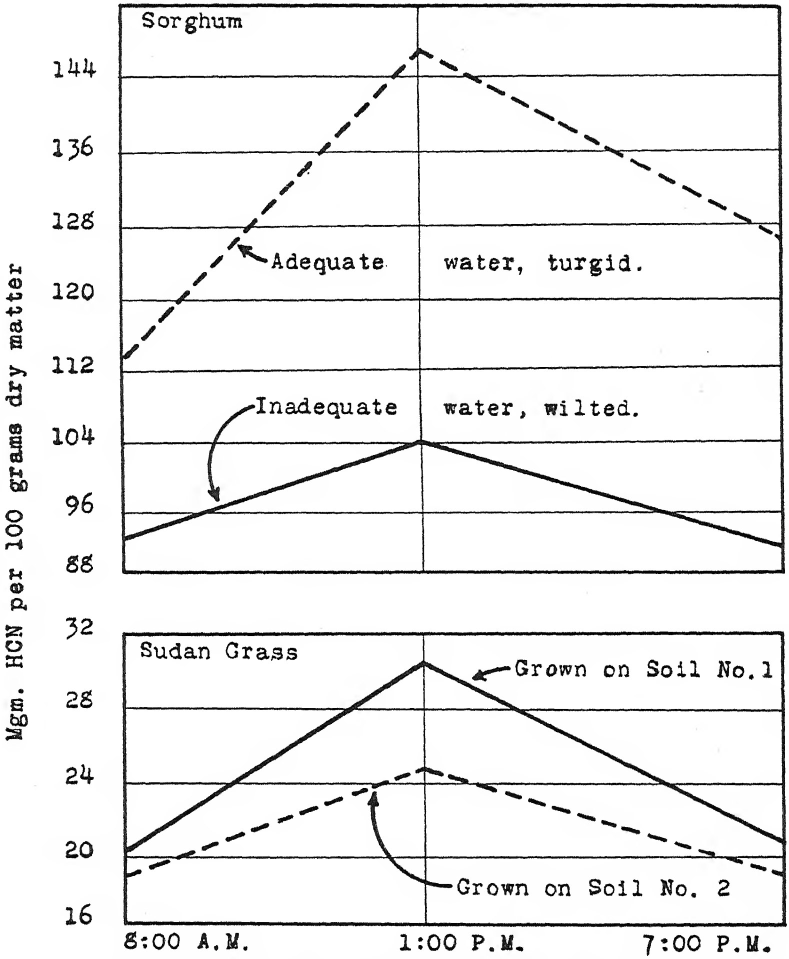

FIG. 4.—Diurnal variation in cyanide content of sorghum and Sudan grass grown in the greenhouse at approximately 1 foot in height.

THE SAFE LIMIT OF CYANIDE CONTENT

During 1937, nearly 500 samples of Sudan grass from farmers' fields were tested for their cyanide content. Reports of these tests were made as to their relative degree of toxicity in accordance with the following schedule:

Mgm HCN per 100 grams dry tissue	Relative degree of toxicity
0–25	Very low (safe to pasture)
25–50	Low (safe to pasture)
50–75	Medium (doubtful)
75–100	High (dangerous to pasture)
>100	Very high (very dangerous to pasture)

Of the 500 samples analyzed, 20 were reported to represent dangerous or very dangerous Sudan grass. Six samples were reported as being doubtful. All the rest of the samples contained less than 50 mgm HCN per 100 grams of dry tissue and were reported to represent grass that was safe to pasture. No cases of poisoning occurred in pasturing according to these recommendations. When fields of Sudan grass were found to be unsafe to pasture, recommendations were made to delay grazing until the grass reached a height of at least 18 inches. The farmers followed this precaution and in no case did they encounter any fatal poisoning. The only fatal case of poisoning of cattle from pasturing Sudan grass in Wisconsin in 1937 that came to the attention of the writers was the Fred Techam case previously mentioned. In this instance, hungry cattle broke into a small paddock of short, green, second growth Sudan grass.

ELIMINATION OF CYANIDE POISONING BY PROPER MANAGEMENT

In view of the results obtained, the following program of Sudan grass management is recommended which not only minimizes the danger of cyanide poisoning but also provides the most pasturage from a given area.

For continuous grazing of Sudan grass during the summer months, it is desirable to have two or more fields of Sudan grass so that the cattle may be rotated from field to field, thus obviating the necessity of pasturing a field when much of the grass consists of small new growth, as is finally the case when a relatively large field is slowly grazed down. Rotational grazing of Sudan grass has other notable advantages. It makes possible the production of more pasturage from a given area because the grass is allowed to get a good start and produce a large amount of leaf surface before being pastured. It is in the actively growing young leaves that much of the carbohydrate and protein manufacture takes place, and if these leaves are grazed off as soon as formed, the grass is prevented, at all times, from having the advantage of a period when rapid manufacture of carbohydrates and proteins and hence rapid growth can take place. In rotational grazing, the grass has the advantage of rapid growth that comes only after a good start is once made. Still another advantage of rotational grazing is that it causes a more uniform removal of all of the old growth and then provides for a rest period during which time the pasture becomes cleansed and thus the pasturage made more palatable again.

To insure a good growth of Sudan grass, soil moisture should be conserved and stored by plowing the land in the fall or early spring so as to aid the entrance of water and then cultivating occasionally in early spring to prevent weed growth and excessive loss of moisture during the interval before the land is sown to Sudan grass. Under Wisconsin conditions, for continuous summer grazing, the first field should be sown during the latter part of May and the second and any others not later than June 15. On well-prepared and fertile land the first field should be ready to graze during the early part of July.

To obtain the most forage, low in cyanide, Sudan grass should not be grazed until it has reached a height of at least 18 inches. When the Sudan grass area is divided into two or more fields, grazing of a smaller area at a time is made possible. This forces the cattle to remove quite completely and uniformly, in a relatively short period, the growth which has accumulated. The proportionately small amount of new growth which is produced during this period is mixed with so much older growth that there is no danger of poisoning. As soon as the first field is grazed down, the cattle are rotated to the second field, where the grass should then be at least 18 inches in height. This gives the grass in the first field full opportunity to produce new shoots and leaves, making possible rapid photosynthesis and growth. When the grass in this first field has again reached a height of 18 inches or more, the field is again ready for grazing. The other field or fields are managed similarly. If other pasture than Sudan grass is available, the cattle may, of course, be rotated from the Sudan grass to that pasture and back again.

To insure hay of low cyanide content, Sudan grass should not be cut until it has reached a height of at least 2 feet. On fertile soils, good palatable hay, high in protein, can be obtained even if the grass is allowed to grow several feet in height.

SUMMARY

The purpose of this investigation was to determine the factors involved in cyanide poisoning of livestock by Sudan grass in order that a program of crop management might be formulated which would eliminate this danger. In the course of this investigation, a rapid chemical method for determining the cyanide content of Sudan grass and sorghum was developed. This method has proved invaluable in elucidating the factors involved and in determining whether or not Sudan grass is safe to pasture. The results obtained are summarized as follows:

1. It is the *short*, *dark* green Sudan grass which is high in cyanide and which is dangerous to pasture. Second growth, after pasturing or removal of a hay crop, when short and dark green is especially dangerous. Sudan grass which is 2 feet or more in height, whether first or second growth, is low in cyanide and is relatively safe to pasture. Sudan grass, short or tall, which is of a pale or yellowish green color is low in cyanide and is relatively safe to pasture.

2. Both from the standpoint of danger from poisoning and possibility of obtaining the most pasture, Sudan grass should usually not be pastured until it has reached a height of 18 inches and better, 2 or 3 feet. This is best accomplished by having two or more fields so that the cattle may be rotated from one field to another.

3. A high level of available nitrogen and a low level of available phosphorus in the soil tend to increase the poison content, while a low level of available nitrogen and a high level of available phosphorus have the opposite effect. A high cyanide content may still occur in short plants, however, especially in the second growth, even though the level of available phosphorus is high. A high level of available

phosphorus along with other favorable growth factors makes it possible for the plant to attain quickly a height of 2 to 3 feet, at which stage it is relatively free of poison.

4. Drought probably operates as a factor, largely by keeping the plants small when they are always much higher in cyanide than when larger. Drought keeps the plants small by withholding water and probably lessening the availability of phosphates to plants much more than that of nitrogen. Fall or early spring plowing followed by cultivation should be practiced on fields to be sown to Sudan grass so as to conserve moisture and prevent the ill effects of drought.

5. When Sudan grass is dried and made into hay without undue exposure and then well stored, the cyanide content does not change greatly. Since it is usually not cut for hay until it reaches a height of 3 feet or more, there is little if any danger of cyanide poisoning from Sudan grass hay. However, if short Sudan grass, high in cyanide, is made into hay, it will be dangerous as a feed.

6. Cattle when turned into Sudan grass of high poison content usually stop eating after about 15 minutes due to the action of the poison. If the animals are not too hungry and are in a high state of vigor, they may stop eating before they take a fatal dose. Cattle vary in the amount of cyanide that it takes to be fatal. If they are in a low state of vigor and very hungry, they are more apt to eat a fatal dose than when the opposite is the case.

7. When there is doubt as to possible danger, samples should be collected and tested for poison. The whole field should be examined carefully. If spots of small Sudan grass are found, samples from each of these should be taken for analysis.

LITERATURE CITED

1. ACHARYA, C. NARASIMHA. Investigations on the development of prussic acid in cholan (*Sorghum vulgare*). Indian Jour. Agr. Sci., 3:851–869. 1933.
2. ALWAY, F. J., and TRUMBULL, R. S. On the occurrence of prussic acid in sorghum and maize. Nebr. Agr. Exp. Sta., Ann. Rpt., 23d: 35. 1909.
3. HADLEY, F. B., and KOZELKA, F. L. Antidotes for hydrocyanic acid poisoning. Vet. Med., 30:79–81. 1935.
4. LEEMAN, A. C. Hydrocyanic acid in grasses. Onderstepoort Jour. Vet. Sci. and An. Ind., 5:97–136. 1935.
5. MANGES, J. D. Cyanide poisoning. Vet. Med., 30:347–349. 1935.
6. MAXWELL, W. Sorghum poisoning. Queensland Agr. Jour., 13:93–98. 1903.
7. MOODY, A. W., and RAMSEY, A. A. Sorghum-Sudan grass hybrids. Agr. Gaz. New South Wales, 40:731–735. 1929.
8. ROGERS, CHARLES F., and BOYD, W. L. Sudan grass and other cyanophoric plants as animal intoxicants. A preliminary report. Jour. Amer. Vet. Med. Assoc., 88:489–500. 1936.
9. SWANSON, C. O. Hydrocyanic acid in Sudan grass and its effect on cattle. Jour. Amer. Soc. Agron., 13:33–36. 1921.
10. ————. Hydrocyanic acid in Sudan grass. Jour. Agr. Res., 22:125–138. 1921.
11. WILLAMAN, J. J., and WEST, R. M. Notes on the hydrocyanic-acid content of sorghum. Jour. Agr. Res., 4:179–185. 1915.
12. WILLAMAN, J. J. Effect of climatic factors on the hydrocyanic-acid content of sorghum. Jour. Agr. Res., 6:261–272. 1916.

CAPILLARY CONDUCTIVITY OF PEAT SOILS AT DIFFERENT CAPILLARY TENSIONS[1]

B. D. Wilson and Sterling J. Richards[2]

Capillary conductivity is a convenient term for expressing the ability of an unsaturated soil to conduct water. The term is defined as the amount of water which in unit time crosses a unit area perpendicular to the direction of flow when the water-moving force is unity. The capillary conductivity of a soil depends not only on the type of soil but also on the moisture content.

In a previous report from this laboratory, Richards and Wilson[3] presented measurements of capillary conductivity for two peat soils. One of the soils was taken from the surface zone of a virgin deposit of woody peat. The other soil was collected from a cultivated area of the same deposit. The area had been tilled annually for a period of about 50 years. In the present report capillary conductivity values are recorded for four other peat soils under varying conditions of moisture. The moisture conditions of the soils are expressed in terms of capillary tension. Embodied in the report is a comparison of the values obtained for the peat soils used in this investigation with the values reported by Richards[4] for three mineral soils of different textures.

METHOD OF PROCEDURE

The method employed in measuring the capillary conductivity of the soils is described in the article by Richards and Wilson, referred to above, hence only a brief description of the method will be given here. The soil to be studied was placed in telescoping brass cylinders between two hollow porous cells. The flow of water to and from the soil took place through the walls of the cells at pressures less than atmospheric pressure. Such pressures are commonly referred to as capillary tensions. Enough soil was placed in the cylinders to form a column of soil about 12 cm in length and 12.1 cm in diameter. In no case during the tests did the soil expand or contract sufficiently to change the length of the column 0.1 cm. The force causing water to move through the soil was supplied by controlling the capillary tensions at the two ends of the soil column at different values. The column of soil was placed horizontally making a consideration of gravitational forces unnecessary. Evaporation of water from the soil was prevented by placing the cylinder containing the soil in an air chamber saturated with water vapor. Burette tubes were employed for reading the flow of water to and from the soil. During the experiments room temperature was controlled automatically at 24.8° ± 0.1° C. Two complete units of the apparatus were available for the work, making it possible to procure individual records for two soils simultaneously.

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[1]Contribution from the Departments of Agronomy and Physics, Cornell University, Ithaca, New York. Received for publication April 6, 1938.

[2]Professor of Soil Technology, Cornell University; and formerly Graduate Assistant in Physics, Cornell University, now Assistant Soil Physicist, New Jersey Agricultural Experiment Station, respectively.

[3]Richards, L. A., and Wilson, B. D. Capillary conductivity measurements in peat soils. Jour. Amer. Soc. Agron., 28: 427–431, 1936.

[4]Richards, L. A. Capillary conductivity data for three soils. Jour. Amer. Soc. Agron., 28: 297–300, 1936.

Capillary conductivity, (K) was calculated from the expression $K = Q/t \times Ld/A\Delta T$, where Q/t is the cc of water per second passing through the soil column, L is the length of the soil column in cm, A is the area of the soil column in square cm, d is the density of water in grams per cc, and ΔT is the difference in capillary tension at the two ends of the column expressed in dynes per square cm.

SOILS USED IN THE INVESTIGATION

Two virgin and two cultivated peat soils were used in the investigation. One of the virgin soils was taken from the surface foot of a peat despoit composed of dark brown, granular woody peat containing an admixture of reed and sedge peat. The deposit is about 4 feet in depth underlain with Chara and shell marl. This soil is designated as peat A (virgin). Another sample of soil taken from the surface foot of a contiguous area which had been cultivated annually for about 20 years is designated as peat A (cultivated, 20 years). This soil having been reduced to a fine state of division during the extended period of cultivation was more uniform in character than was peat A (virgin).

A third sample of soil, made up largely of grayish brown, well-decomposed woody peat, and designated as peat B (virgin, screened), was collected from the upper foot of an uncleared despoit. The sample was screened to remove the larger fragments of wood and the roots of recent vegetation. Screening made the soil more or less uniform in character. The deposit from which the sample was taken is about 3 feet in depth resting on non-calcareous gray sand. A fourth sample of soil, designated as peat C (cultivated, 2 years), was collected from a deposit which had been cleared two years previous to the time of collection and which had been tilled during two cropping seasons. The soil was composed of grayish brown woody peat and it was lumpy from coarse woody debris. The deposit was approximately 30 feet in depth underlain with calcareous, grayish blue clay.

Air-tight containers were used for storing the soils until they were placed in the telescoping cylinders of the apparatus. At that time the soils had lost little moisture, and with the exception of peat B (virgin, screened), they possessed much of the original field structure. In filling the cylinders the soil was subjected to some tamping in order that large voids would not exist in the soil column. However, an attempt was made to maintain the characteristic structure of the soil.

CAPILLARY CONDUCTIVITY OF THE SOILS

Each of the soils took up water from the cells before appreciable amounts of water commenced to flow through the column of soil. Calculations of capillary conductivities were made from data taken after a steady flow of water through the system was established. In the report by Richards and Wilson[5] a steady flow was assumed to exist when the amount of flow to and from the soil column differed by less than 1%. Because this relationship was not attained at low conductivities, those authors assumed that an insufficient period of time had elapsed for the establishment of steady flow.

The present work served to show that the rate of flow of water into and from the soil was never equal. For a given period of time, the amount of water flowing from the soil became a definite fraction of the amount of water flowing into the soil. After that the ratio of inflow to outflow remained constant. The establishment of this relationship

[5]See footnote 3.

was used by the writers as the criterion of steady flow. At that state of flow the difference between the values for inflow and outflow, divided by the time interval, gave, in most cases, a constant value of about 2.5×10^{-5} cc/sec. This seemed to indicate that water was lost from the system at a constant rate. The rate of loss varied from less than 1% to approximately 100% of the inflow. In computing the capillary conductivities of the soils the rate of inflow was used, because if water was lost from the system, the most likely source of loss was from the burette used for collecting the outflow of water from the soil.

Recorded in Table 1 are the capillary conductivities of the soils at different capillary tensions. These data are presented graphically in Fig. 1. The graphs of the figure were drawn using as ordinates the logarithms of the values for capillary conductivities which are shown in the last column of Table 1, and as abscissas the corresponding values for capillary tensions. At equal tensions the conductivity of peat A, which had been tilled for more than 20 years, was greater than was that of any of the other soils. Its conductivity was considerably greater than was that of the virgin soil taken from the surface foot of the same peat deposit. A comparison of the conductivities of the two virgin soils shows the one that was screened to have higher values at the higher tensions. At comparable tensions the screened soil did not differ greatly in conductivity from the soil that had been cultivated for two cropping seasons. The order of the magnitude of the capillary conductivities of the several soils suggests that particle size was an important factor in controlling the flow of water through the soils, the soils of finer texture having the greater capillary conductivities. One of the oustanding features of Fig. 1 is the relatively

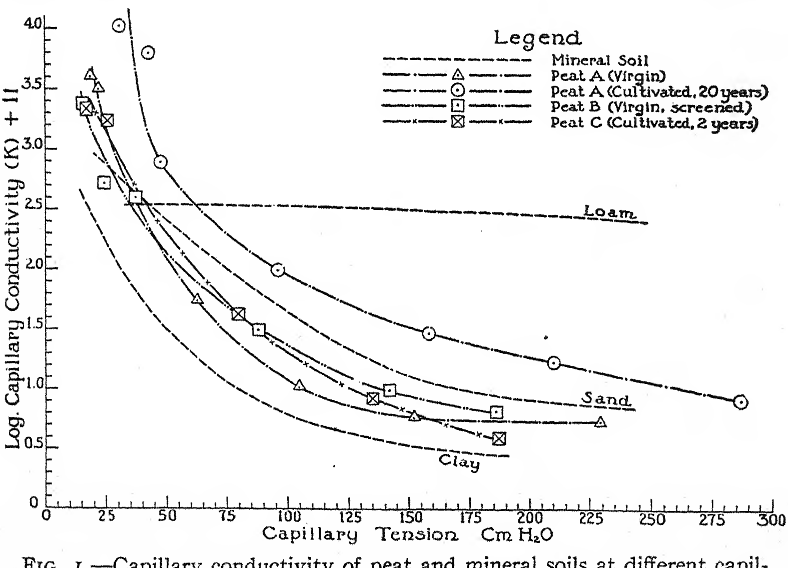

FIG. 1.—Capillary conductivity of peat and mineral soils at different capillary tensions.

high capillary conductivity of peat A, cultivated. The tendency of the graphs for the other peat soils to converge at the lower tensions indicates that, at those values, the soils did not differ greatly in the ability to conduct water.

TABLE 1.—*Capillary conductivity of water in peat soils at different capillary tensions.*

Date of record	Capillary tension, equivalent water column in cm	Capillary conductivity, seconds X 10^{11}	Log K+11
	Peat A (Virgin)		
Aug. 1	18.6	4,010	3.60
Aug. 19	22.0	3,120	3.49
Oct. 6	152.3	5.9	0.77
Oct. 22	104.8	10.4	1.02
Nov. 30	62.5	54.1	1.73
Dec. 23	228.9	5.4	0.73
	Peat A (Cultivated, 20 Years)		
Aug. 1	30.4	1,040	4.02
Aug. 19	42.6	632	3.80
Oct. 3	158.3	30	1.48
Oct. 22	95.7	99	2.00
Nov. 28	47.5	781	2.89
Dec. 11	210.2	17.3	1.24
Dec. 23	287.1	8.4	0.92
	Peat B (Virgin, Screened)		
Jan. 3	15.8	2,360	3.37
Jan. 16	36.8	399	2.60
Feb. 6	142.0	10	1.00
Mar. 10	23.6	525	2.72
Mar. 29	88.2	31.8	1.50
Apr. 19	186.3	6.7	0.83
	Peat C (Cultivated, 2 Years)		
Jan. 17	25.1	3,460	3.54
Feb. 5	135.1	8.4	0.92
Mar. 10	17.2	2,180	3.34
Mar. 26	79.4	42.8	1.63
Apr. 19	186.9	4.9	0.69

Graphs are also shown in Fig. 1 for three mineral soils, and they serve as a basis for comparing the capillary conductivities of organic and inorganic soils. The comparison seems admissible because essentially the same method of procedure was employed for measuring the capillary conductivities of the two types of soils. The graphs for the mineral soils were constructed from data reported by Richards.[6] An inspection of Fig. 1 reveals a similarity in the shape and the position of the graphs for the peat soils and the sandy and clay soils. The graph for the loam soil is distinctly different in character. The nature of the graph implies that the capillary conductivity of the loam soil is not materially affected by changes of considerable magnitude in capillary tension. This quality may be associated with the texture of the loam soil.

[6]See footnote 4.

The graphs of Fig. 1 substantiate the conclusion drawn by Richards and Wilson[7] that at relatively low tensions the capillary conductivities of peat soils exceed those of mineral soils, and they suggest that at relatively high tensions the same order would hold for the finer-textured mineral soils.

MOISTURE CONTENT AND CONDUCTIVITY

At the conclusion of the measurements of capillary conductivity each soil was removed from the apparatus and the moisture content of the soil was determined. The percentages of moisture noted in the last column of Table 2 represent the amounts of water which were present in the soils at the time of the lowest observed conductivity measurements. Included in the table are similar values for the three mineral soils referred to in Fig. 1.

TABLE 2.—*Moisture content of soils at the lowest observed capillary conductivity.*

Soil	Capillary tension, equivalent water column in cm	Capillary conductivity seconds X 10^{11}	Moisture %, dry soil
Peat A (virgin)	229	5.4	209
Peat A (cultivated, 20 years)	287	8.4	148
Peat B (virgin, screened)	169	6.7	182
Peat C (cultivated, 2 years)	169	4.9	111
Greenville loam	597	72.7	15
Sandy Soil	243	7.0	5
Preston clay	149	3.3	42

An inspection of Table 2 shows that, at high tensions, the capillary conductivity in peat soil is low even though the moisture content is high. The highest capillary tensions used for the respective soils ranged from 169 to 287 cm of water and the corresponding moisture contents, expressed in terms of dry soil, ranged from 111 to 209%. It may be seen in Table 2 that, for both the peat and the mineral soils, the soil containing the highest percentage of moisture did not necessarily possess the greatest capillary conductivity. The relation of the values shown in the table to the ability of the soils to supply water to growing plants is not known; nor is it known at the present time what differences in conductivity may be required to cause appreciable differences in plant response or cultural practices. It is felt, however, that the laboratory measurements of conductivity give a true indication of the relative moisture transmitting property of the soils tested.

SUMMARY

Studies were made of the capillary conductivity of water in four peat soils for varying capillary tensions. The conductivities of the soils were found to decrease rapidly and continuously with increasing values for capillary tension. To measure conductivities below the

[7]See footnote 3.

values recorded in this report would necessitate a modification of the apparatus employed in the work in order to avoid moisture losses.

An increase in the capillary conductivity of peat soil seems to accrue from prolonged cultivation owing to a type of structure resulting from cultural practices.

Certain comparisons are made between the capillary conductivity of peat and mineral soils and of the moisture content of the soils at low conductivity measurements. The conductivity of peat soil was found to be extremely low in the presence of relatively large amounts of moisture.

More information is needed before the significance of the conductivity values which are reported can be interpreted with respect to the capacity of the soils to supply water to growing plants.

THE ESTABLISHMENT OF LOW HOP CLOVER, *TRIFOLIUM PROCUMBENS*, AS AFFECTED BY TIME OF SEEDING AND GROWTH OF ASSOCIATED GRASS[1]

E. A. Hollowell[2]

THE low hop clover (*Trifolium procumbens*) and the least hop clover (*T. dubium*) are winter annuals widely distributed throughout the southeastern states, although neither species is indigenous to this country. The least hop clover and to a less degree the low hop clover also occurs in many sections of the Pacific Northwest.

In the northern part of the southeastern states the low hop clover predominates, but in the southern part the least hop clover is more abundant. In between there is a wide transition zone where there is an intermingling of both species. When the low hop clover is introduced into the southern part of the United States, it is slightly more productive than the least hop clover, although on most soils it may not become the dominant species unless minerals are supplied.

Both species are valuable in pastures supplying early spring pasturage and increasing the fertility of the soil for the companion grass. If permitted to bloom, hop clovers produce an abundance of seed since they are self-fertile and self-pollinating and are tolerant of variable environments.

In many places the occurrence of either of the species is sporadic, being abundant in certain years and scarce in others. Since the seeds of these species germinate in the fall, the hazards in establishment are great as the very small seed must be near or on the soil surface when germinating. While it appears that hop clover is best adapted to a grass habitat, observations suggest that the competitive effect of the associated plants during the time of establishment of the young clover seedlings may be one of the factors determining their irregular occurrence. As a part of a life history study this experiment was designed to determine the effect of the height of growth of the associated grass and of the date of seeding on the stand establishment of hop clover and whether stands can be established in cultivated soil.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Bureaus of Animal Industry and Dairy Industry, U. S. Dept. of Agriculture, and the Agricultural Experiment Stations of Kentucky, Missouri, North Carolina, Tennessee, and Mississippi, and the Georgia Coastal Plain Station. Received for publication April 13, 1938.

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METHOD OF PROCEDURE

Since the hop clover species (*T. procumbens* and *T. dubium*) are so similar in growth relationships only the low hop clover (*T. procumbens*) was used. It is believed that the results obtained from one will apply to the other. The experiment was begun in 1934 at Beltsville, Md.,[3] Statesville, N. C., Lexington, Ky., Columbia and Grain Valley, Mo., Tifton, Ga., Jeanerette, La., and Columbia, Tenn.

The plats were located in pastures at some places and elsewhere on established sod where areas covered with unclipped or non-grazed grass were selected. The height and density of the turf varied between places and in different years at the same place. A well-prepared, firm seedbed was made for the cultivated plats which were usually not adjacent to the seedings made on the sod.

Monthly plantings were made from September to March but at most places after the first year the late winter and early spring seedings were eliminated since they were generally unsatisfactory. Seedings were usually made from the first to the fifth of the month on square rod plats, on closely clipped grass turf, on unclipped or tall grass plats, and at certain locations on cultivated soil. During the first year the dates of seeding and the differential grass treatments were made on contiguous plats but later were randomized and replicated.

Seedings of the first year were made at the rate of 3 pounds per acre of 100% germinable inoculated seed, but were increased to 10 and 40 pounds per acre for the second and third years, respectively, in order to have more dense stands for recording contrasts.

Other related investigations have shown that these heavier rates of seeding did not approach the amount that is normally produced by good stands. All seedings were broadcast without subsequent treatment.

The grass on the closely clipped plats was cut from 1 to 2 inches in height and removed immediately before seeding and was generally kept clipped thereafter to simulate close grazing until growth ceased in the fall.

Records on height and density of the grass and stand and development of the clover were taken from seeding until the clover blossomed in the spring. At certain locations animals were allowed to graze the plats in the spring and elsewhere the clover was permitted to make full growth. At a few places the same plats were used during the succeeding years to determine whether the stands could be maintained.

Since this study was conducted at several different locations the results are grouped into two divisions according to the growth period of the grass with which the clover plantings were made.

SEEDINGS WITH NORTHERN GRASSES

The seedings at Beltsville, Md., Lexington, Ky., and Grain Valley, Mo., were made on pasture turf principally composed of Kentucky bluegrass (*Poa pratensis*); at Columbia, Mo., on an association of redtop (*Agrostis alba*), Canada bluegrass (*Poa compressa*), and Kentucky bluegrass; while at Statesville, N. C., orchard grass (*Dactylis glomerata*) was the dominant species intermixed with redtop (*Agrostis alba*), tall oat grass (*Arrhenatherum elatius*), timothy (*Phleum pratense*), Korean lespedeza (*Lespedeza stipulacea*), and common and Kobe lespedeza (*Lespedeza striata*). No seedings were made on cultivated soil at Beltsville, Lexington, and Grain Valley. Table 1 gives the results of this study. The results at different locations are not

[3]National Agricultural Research Center.

comparable since the various environmental factors differ. That more complete stands were obtained when the seedings were made in short than in the tall grass is significant. At all locations September or October seedings proved to be superior to the later ones.

At Beltsville during the first week of October 1935 a thick stand of volunteer hop clover was observed in closely cut plats of the September, October, and November 1934 seeding, indicating successful establishment under the close fall clipping practice.

The 1934 seeding at Lexington was grazed by sheep in the spring of 1935 and, as at Beltsville, the hop clover was kept closely grazed until the plants died. The grass on the closely clipped plats of the 1935 seedings was clipped early before the September seeding, but was not cut at later intervals. The grass made a heavy fall growth and this may have contributed to a reduction of the stands of clover. The 1936 seedings were on grass that was slightly thinner than the previous years, due to severe summer drought. The germination on all plats was relatively high this year. The clover plants growing with the uncut grass, however, were spindling, yellowish in color, while those with the short grass were short, thrifty, and of a normal color. In the spring of 1937 when the clover was blooming, the grass of the clipped plats was 2 to 4 inches shorter than that of the unclipped. These same plats were continued in the fall of 1937 with a volunteer seeding. All plats were clipped in late August to a height of 3 inches and in early October the short clipped plats of 1936 were clipped to a height of 1½ inches. In November 1937 the stands on the short clipped grass were 100%, while those on tall grass plats were 35 to 50%. In the clipped plats the plants were thrifty and a normal green while those of the unclipped plats were weak and yellowish in color and it is believed that these will not survive the winter. This pasture was moderately grazed with sheep during the spring of 1937.

At Columbia, Mo., the differences between the stands on the clipped and unclipped plats of the 1935 seeding were not so wide as might be expected with more dense stand and fall growth of the grass. This condition of the grass undoubtedly resulted from the effects of successive years of drought. These plats were not grazed or cut thereby permitting a volunteer seeding. The volunteer seeding and hard seed of the previous seeding produced excellent stands in the fall of 1936, but the grass had been killed by the summer drought and no differences were apparent between the treatments. In contrast to Columbia, Mo., the 1936 seeding at Grain Valley was made on a very dense stand of grass which had not been grazed or clipped during the 1936 season. Volunteer seeding in the fall of 1937 was heavy and the plats are to be continued to determine whether stands may be maintained.

At Statesville the turf of the non-clipped grass plats was more dense in 1935 than in 1936. Late winter and early spring seedings at Statesville germinated and resulted in fair stands, which failed to make much growth or to reproduce. Stands from the September seeding were seriously reduced by an intense drought after a favorable period for germination. While the seedings on the cultivated soil failed to approach the same density of stands as those seeded with grass, the

TABLE 1.—*Estimated percentage stand and height of clover at blooming period of low hop clover (Trifolium procumbens) seeded on tall and short grass and cultivated soil at Beltsville, Md., Lexington, Ky., Statesville, N. C., Columbia, Mo., and Grain Valley, Mo., during the years 1934–1937.*

Treatment of plats	Date of seeding														Condition and density of grass at seeding date
	September		October		November		December		January		February		March		
	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	
Beltsville, Md., 1934–35															
Clipped grass	70	7–9	70	7–9	70	7–9	0	—	0	—	0	—	0	—	Turf dense, uncut grass 7–9 inches high; considerable mature grass
Non-clipped grass	T*	—	T	—	T	—	0	—	0	—	0	—	0	—	
Lexington, Ky., 1934–35															
Clipped grass	40	—	50	—	10	—	0	—	0	—	0	—	0	—	Turf very dense, uncut grass 8 inches high; much matted mature grass on all plats
Non-clipped grass	T	—	T	—	T	—	0	—	0	—	0	—	0	—	
Statesville, N. C., 1934–35															
Clipped grass	5	6	50	6	60	6	50	6	50	4	50	2	50	2	Turf somewhat open, uncut grass 4–6 inches high
Non-clipped grass	5	6	10	6	10	6	5	6	50	4	50	2	50	2	
Cultivated soil	5	10	5	10	20	10	20	8	5	6	5	4	5	3	
Beltsville, Md., 1935–36															
Clipped grass	90	—	90	—	25	—	0	—	0	—	0	—	0	—	Turf dense, uncut grass 4–6 inches high somewhat patchy because of light grazing
Non-clipped grass	25	—	25	—	T	—	0	—	0	—	0	—	0	—	

Lexington, Ky., 1935–36															
Clipped grass	50	4–6	50	4–6	50	2–4	50	2–4	50	2–4	95	0.5–1.5	95	0.5–1.5	Turf very dense, uncut grass 5–8 inches high, much mature grass
Non-clipped grass	T	—	T	—	T	—	T	—	T	—	T	—	T	—	
Statesville, N. C., 1935–36															
Clipped grass	50	—	50	—	0	—	0	—	0	—	0	—	0	—	Turf open, uncut grass 3–5 inches high; fall growing condition unfavorable
Non-clipped grass	30	—	50	—	0	—	0	—	0	—	0	—	0	—	
Columbia, Mo., 1935–36															
Clipped grass	75	—	90	—	25	—	T	—	T	—	T	—	0	—	Turf somewhat open, uncut grass 3–5 inches high
Non-clipped grass	30	—	75	—	5	—	T	—	T	—	T	—	0	—	
Cultivated soil	0	—	0	—	0	—	0	—	0	—	0	—	0	—	
Beltsville, Md., 1936–37															
Clipped grass	90	10	90	10	—	—	—	—	—	—	—	—	—	—	Turf dense, uncut grass 6–10 inches high
Non-clipped grass	T	—	T	—	—	—	—	—	—	—	—	—	—	—	
Lexington, Ky., 1936–37															
Clipped grass	99	5–6	76	5–7	—	—	—	—	—	—	—	—	—	—	Turf dense, uncut grass shorter than normal, 4–6 inches high
Non-clipped grass	26	5–7	12	5–7	—	—	—	—	—	—	—	—	—	—	
Grain Valley, Mo., 1936–37															
Clipped grass	10	6	T	—	—	—	—	—	—	—	—	—	—	—	Turf very dense, uncut grass 6–10 inches high; much mature grass not cut or grazed in 1936
Non-clipped grass	T	—	T	—	—	—	—	—	—	—	—	—	—	—	

*Trace.

growth of the plants was greater. In 1935 the growth of the companion grass was short due to drought, making the height of the grass on both the clipped and non-clipped plats the same, and in the spring of 1937 all plats had nearly perfect stands, though not quite so dense on the non-clipped as on the clipped plats.

SEEDING WITH SOUTHERN GRASSES

Bermuda grass (*Cynodon dactylon*) was the companion of the seedings made at Tifton in 1934 and 1936, and at Columbia, Tenn., while at Jeanerette seedings were made in an association of Bermuda grass, foxtail (*Setaria* sp.), and vasey grass (*Paspalum Urvillei*). The 1935 seedings at Tifton were with carpet grass (*Axonopus compressus*). In contrast with Kentucky bluegrass, Bermuda grass does not form a dense mat at the surface of the soil, particularly in soils at the lower fertility levels. Carpet grass, however, does form a thick ground cover. The results of these plantings are given in Table 2.

The results at Tifton are the most comprehensive of those where planting was made with the southern grasses. Early seedings under all conditions were the least successful. Fall droughts interspersed by short wet periods and accompanied by temperatures conducive to the rapid evaporation of the surface soil moisture resulted in the death of the young seedlings. Regardless of the seeding date, plantings made in cultivated soil failed to produce good stands. While partial stands on sod were obtained for all seeding dates, the February and March plantings were the least successful and resulted in meager growth. The clover seedings on the non-clipped Bermuda grass plats generally produced better stands than those on the clipped turf. In contrast to the results with seedings on Bermuda grass the seedings on carpet grass produced the best stands under the clipped grass treatment. The hop clover growing in the 1934–35 plats was allowed to seed and volunteer in the fall of 1935 without an additional seeding. All the plats were clipped according to the clipping schedule of 1934. The stands in the spring of 1936 for the original September, October, November, and December 1934 seedings on both clipped and non-clipped plats varied from 50 to 100%. A similar treatment was given in 1936 as in 1935, resulting in a more dense stand of clover on the clipped than on the non-clipped plats. The stand of Bermuda grass on these plats was decidedly thicker than during the previous years.

At Columbia, Tenn., the early seedings produced good stands on both the clipped and non-clipped grass, while the seedings made on cultivated soil produced poorer stands than those seeded with grass.

At Jeanerette the 1934 September seeding was delayed until the latter part of the month. The turf composed principally of Bermuda grass was somewhat open even though casual observation would indicate a dense cover. The results of the 1935 planting were similar to those of the previous year as shown in Table 2. Only at Jeanerette have any of the seedings on cultivated soil equalled the seedings made on turf.

The experiment at West Point, Miss., in 1934 unfortunately was located in a wet situation resulting in a failure. In 1936 excellent

stands were obtained in a seeding on both clipped and non-clipped grass at seeding dates of September 15 and October 15, respectively. An excellent volunteer stand occupied all of these plats in November 1937. The companion grass, principally Bermuda with some dallis grass (*Paspalum dilatatum*), did not make a dense turf.

DISCUSSION AND CONCLUSIONS

In interpreting the results consideration must be given to the ecological factors of light, soil moisture and temperature, and soil fertility as related to the germination and development of the hop clover and the growth habits of the companion grass. Since the northern and southern grasses differ so widely it seems advisable to relate the discussion to the data as presented.

The results at Beltsville, Md., Lexington, Ky., Statesville, N. C., and Columbia and Grain Valley, Mo., clearly indicate that the tall grass inhibits the successful establishment of hop clover regardless of date of seeding. With the advent of cool, moist weather the northern grasses begin rapid growth spreading vegetatively and developing a dense turf thus competing with the seedling development of hop clover. Climatological data for the different years indicate that under such environments soil moisture has not been the limiting factor nor has soil temperature, since stands were established on the clipped plats. The lack of sufficient light is believed to be the principal reason for failures. In a few places, however, thin stands have been obtained in tall grass with the development of spindling plants which died during winter.

The association of hop clover with grass appears to be beneficial to establishment and survival of the clover, for at Statesville the stands in the cultivated soil plats were much thinner than those planted with grass and at Columbia, Mo., all seedings on the cultivated soil failed in stand establishment. Observations indicate that the grass is beneficial in reducing the hazard of rapid evaporation with subsequent drying of the soil surface thereby influencing the germination or decreasing the mortality of the clover seedlings in their early establishment. The results also clearly indicate that in the latitude where the experiments were conducted September and October seedings will give the most nearly complete stands. While stands from December, January, and February seedings have been obtained during certain favorable years, spring growth of the plants has not been significant and reproduction has failed. It has also been shown that increased rates of seeding to offset the hazards of unfavorable conditions when the initial stands are being established may be a necessary prerequisite to successful establishment of a stand and the development of a seed equilibrium.

When hop clover was planted with southern grass the results present less conclusive evidence of the relationship of the competitive effect of grass on stand establishment. With most all seedings on Bermuda grass, just as good or better stands were obtained in non-clipped as in clipped grass. The results with carpet grass for one year at Tifton show superior stands on the clipped plats. These differences may be attributed to differences in growth habits of these grasses.

TABLE 2.—*Estimated percentage stand and height at blooming period of low hop clover (Trifolium procumbens) seeded on tall and short grass and cultivated soil at Tifton, Ga., Columbia, Tenn., and Jeanerette, La., during the years 1934–1937.*

Treatment of plats	Date of seeding														Condition and density of grass at seeding date
	September		October		November		December		January		February		March		
	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	% stand	height, inches	
Tifton, Ga., 1934–35															
Clipped grass	18	1–4	20	4–6	13	2–4	30	2–4	23	1–2	15	1–2	0	—	Bermuda grass thick stand uncut grass 6–8 in. in height; turf open at soil surface
Non-clipped grass	25	4–10	45	4–10	20	4–8	75	6–10	67	4–6	23	1–2	13	—*	
Cultivated soil	10	1–4	20	2–6	30	2–4	30	2–3	15	1	18	1–2	0	—	
Columbia, Tenn., 1934–35															
Clipped grass	75	10	85	10	15	8	15	8	T	—	T	—	T	—	Bermuda grass thick stand, uncut grass 4–6 in. in height; turf open at soil surface
Non-clipped grass	75	10	80	10	15	8	15	8	T	—	T	—	T	—	
Cultivated soil	40	9	15	7	5	—	T	—	T	—	T	—	T	—	
Jeanerette, La., 1934–35															
Clipped grass	70†	8–10	—	—	50	8–10	—	—	1	—	1	—	1	—	Bermuda and vasey grass, uncut grass 6–12 in. in height; thick stand, turf open at soil surface
Non-clipped grass	50	10–14	—	—	50	8–10	—	—	1	—	1	—	1	—	
Cultivated soil	75	4–8	—	—	50	4–6	—	—	33	6–8	1	—	1	—	

							Tifton, Ga., 1935–36								
Clipped grass	10	6	60	8	75	8	60	8	20	8	5	6	5	6	Carpet grass thick stand, 4–6 in. in height; thick ground cover
Non-clipped grass	10	6	20	6	40	6–8	60	6–8	50	6–8	5	6	T	—	
							Jeanerette, La., 1935–36‡								
Clipped grass	—	—	70	3	75	4	75	4	—	—	Failed		Failed		Turf open, uncut grass from 6–12 in. in height; mostly Bermuda with foxtail and vasey
Non-clipped grass	—	—	80	4	85	5	85	6	—	—	—	—	—	—	
Cultivated soil	—	—	70	2	75	2	70	3	—	—	—	—	—	—	
							Tifton, Ga., 1936–37								
Clipped grass	10	6	20	6	40	8	60	8	50	8	5	6	0	—	Bermuda grass, thick stand, uncut grass 6–8 in. in height; turf open at soil surface
Non-clipped grass	10	6	60	10	75	10	60	8	20	8	0	—	5	6	

*Discarded on account of volunteer white clover.
†Seedings made Sept. 27, 1934.
‡Seedings made on Oct. 17, Nov. 2, and Nov. 27, respectively.

The stems developed from the spreading under-ground rhizomes of Bermuda grass do not tiller where they emerge through the soil surface. This results in an openness in the turf at the surface of the soil.

In contrast to the Bermuda grass, carpet grass spreads vegetatively by creeping stems which make a dense tight mat over the soil surface. It is believed that this growth habit is responsible for the differences in behavior of the hop clover seedings as related to clipped and non-clipped treatments.

The results at Tifton clearly indicate that late fall is the preferable time for seeding. At Jeanerette in 1934 the late September seeding was superior to the November seeding. In the southern part of this region soil moisture and temperature appear to be important ecological factors in the establishment of the clover. When seeded in early fall the grasses are still competing vigorously, both soil and atmospheric temperatures are relatively high, and periods of dry weather are not uncommon. The interspersing of short rainy periods with a rapid drying of the soil surface and dry weather are fatal to germinating seed and young seedlings. As the fall progresses with a lowering of temperature the southern grasses become dormant, reducing their demand for moisture and, by shading, conserve it at the soil surface by reducing evaporation. This protection afforded by the non-clipped companion grass favors the clover since it is not of sufficient density to reduce the light necessary for its establishment. This interaction of the ecological relationships is evident from the planting at Columbia, Tenn., where at a more northern latitude the early plantings produced the best stands.

As the fertility of the soil increases supporting a more dense stand and growth of grass or cover at the soil surface, fall clipping or close grazing may be expected to facilitate the establishment of hop clover as was observed at Tifton on the 1936 volunteer plats. The results at Tifton also indicate that a short dense cover of carpet grass will protect the developing clover seedlings similar to a less dense cover but taller Bermuda grass.

The establishment of good stands on cultivated soil at Jeanerette and the failure at other places in the southern states appears to be the result of a favorable soil relationship. The heavy clay soils at Jeanerette are low lying, retentive of moisture, and higher in organic matter than the other soils where seedings were made without grass as a companion plant.

Observations at other localities have shown that the same relationships exist with other Trifolium species such as Persian clover (*Trifolium resupinatum*) and white clover (*Trifolium repens*) where the latter behaves as a winter annual.

THE RELATION OF LIGNIFICATION OF THE OUTER GLUME TO RESISTANCE TO SHATTERING IN WHEAT[1]

O. A. Vogel[2]

THE problem of shattering of wheat is of greater importance to the wheat industry in the Pacific Northwest than in any other major wheat-producing area of the United States. In this area the harvest season covers a period of two to three months and a large portion of the grain often stands in the field two or three weeks after maturity. During this extended harvest season the standing grain is frequently subjected to hot winds of high velocity and low relative humidity, causing heavy losses of grain from shattering. Losses of 5 to 15% have been frequently observed among several of the commercial varities in the Palouse and neighboring areas during recent years. Other varieties having greater resistance to shattering but growing under similar conditions lost comparatively little or no grain. However, the more resistant varieties are sometimes difficult to thresh and thereby produce an excess of cracked kernels and unthreshed single-grained tip spikelets, both of which are discriminated against in the grain trade.

In the present wheat improvement program attempts are being made to select strains and hybrids that possess enough resistance to prevent much of the shattering in the field and still thresh reasonably easy. In the course of this work it has become obvious that a better understanding of the nature of resistance to shattering is needed. This need has led to a study of the structural details at the breaking points in the basal portions of the outer glumes of the wheat spikelet. The outer glumes were chosen for this study because, from the standpoint of resistance to shattering, their primary function seems to be to help hold the other flowering parts in place.

MATERIAL AND METHODS

The four central spikelets from each of several typical heads of several varieties of wheat representing varying degrees of resistance to shattering were collected at six stages of growth, namely, late boot; flowering; early, medium, and stiff dough stages; and at maturity. The grains were carefully removed leaving intact the lemmas and outer glumes. The remaining portion of each spikelet of the five immature stages was killed in alcohol-formalin-acetic acid solution, dehydrated,

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Farm Crops Section of the Washington Agricultural Experiment Station. Scientific Paper No. 384, College of Agriculture and Experiment Station, State College of Washington. Received for publication March 10, 1938.

[2]Assistant Agronomist, Division of Cereal Crops and Diseases. The writer is grateful for the use of the equipment of the Department of Botany, State College of Washington, and for the interest and many helpful suggestions of Dr. H. F. Clements, formerly Associate Professor, and Dr. Hanna A. Aase, Associate Professor of that Department, and the advice and comments of Dr. E. F. Gaines, Cerealist, of the Agronomy Department.

and infiltrated with paraffin. Those of the mature stage were placed directly into paraffin at 175° to 200° C for approximately 1 hour.

To determine the location at which the break occurs, the outer glumes of some of the mature spikelets were bent back enough to break as much as possible of the tissue at the breaking point without severing completely the two parts.

Considerable difficulty was experienced in cutting the material into desirably thin sections. Material gathered in the boot and flowering stages was cut successfully in 16-micron sections with a rotatory microtome. The older material, because of its brittle nature, necessitated cutting at thicknesses of 40 and 60 microns with a sliding microtome.

Both cross and longitudinal sections were cut through the basal portions of the glumes. The longitudinal sections were cut parallel to the broad side of the spikelet. The sections from each glume were arranged serially on from one to three slides.

Albumin was used to fix the sections on slides from material in the boot and heading stages, but LePagé's glue with potassium bichromate was more satisfactory for the later stages. The sections were then stained with malachite green and Bismarck brown and mounted in balsam.

EXPERIMENTAL RESULTS

It appeared desirable to determine first the location at which the glume breaks from the rachis. This is shown by the two longitudinal sections in Fig. 1, A and B, which were taken from a mature glume of the variety Sherman (C. I. 4430). Measurements of these sections and similar measurements of other sections indicate that the break usually occurred between 0.1 and 0.2 mm above the inside base of the glume.

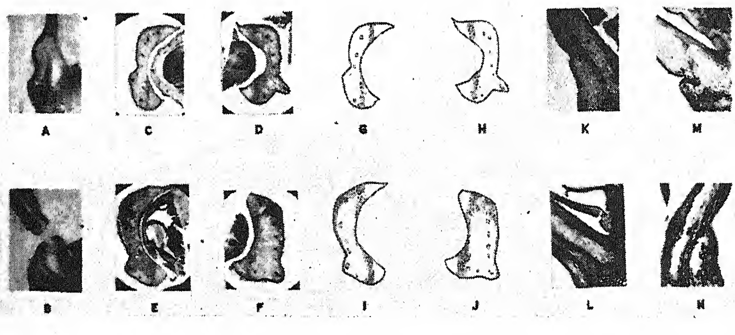

FIG. 1.—Photomicrographs of longitudinal and cross sections of the basal portion of wheat glumes. A, B, longitudinal sections of mature glume of Sherman wheat showing the breaking point; C, D, cross sections of 1st and 2d glumes of a spikelet of White Odessa (C. I. 4651); E, F, cross sections of 1st and 2d glumes of a spikelet of White Odessa (C. I. 4655); G, H, same as C and D with lignified areas stippled; I, J, same as E and F with lignified areas stippled; K, longitudinal section of Sherman at early dough stage of maturity; L, longitudinal section of White Odessa (C. I. 4655) at early dough stage of maturity; M, longitudinal section showing buckling of outer epidermis at the breaking point; and N, longitudinal section of mature glume of White Odessa (C. I. 4655).

Cross sections taken from the region at which the glume breaks were studied next. Sections C and D of Fig. 1 are from the breaking points of each of the two outer glumes of a spikelet of White Odessa (C. I. 4651) in the medium-late dough stage of growth. Similarly, sections E and F are from White Odessa (C. I. 4655). These represent varieties very susceptible and very resistant, respectively, to shattering. The lignified tissues are less distinct in the photomicrographs than under the microscope so sections C, D, E, and F are shown in outline in G, H, I, and J, respectively, with the lignified tissues stippled.

It should be noted that the first and second glumes of the same spikelet have a different pattern. Consequently, in order to compare one variety with another properly corresponding glumes of each variety must be used.

It is probable from the cross sections that, insofar as the outer glumes are concerned, the greater shattering resistance of White Odessa (C. I. 4655) is due to greater thickness and more lignified tissue. Furthermore, the smaller proportion of lignified tissue in the first glume (sections G and I) apparently accounts for this glume being usually more easily broken from the spikelet.

The relative proportion of lignified tissue in the basal portion of the outer glumes of 11 varieties of common wheat (*Triticum vulgare*) and 1 of emmer (*T. dicoccum*), compared with the 2 strains of White Odessa as standards, is shown in Table 1. A direct correlation was found between the relative proportion of lignified tissue and the shattering resistance class among the varieties tested. However, when the difference in lodging resistance was small as, for example, that between Fortyfold and its somewhat more resistant selection Golden, possible differences in lignified tissue were obscured by the variability between individual spikelets. A similar difficulty was encountered in comparing Kharkof with the somewhat less resistant variety Sherman. Further efforts to measure relatively small differ-

TABLE 1.—*Shattering resistance and relative lignification of the basal portion of the glumes in 11 varieties of common wheat and 1 of emmer.*

Variety	C.I. No.	Shattering resistance	Lignification
		Common Wheat	
Garnet	8181	Very susceptible	Very slight
White Odessa	4651	Susceptible	Slight (Fig. I, G, H)
Fortyfold	6176	Susceptible	Slight (Fig. I, G, H)
Mosida	6688	Susceptible	Slight (Fig. I, G, H)
Golden	10063	Slightly susceptible	Slight (Fig. I, G. H)
Sherman	4430	Slightly resistant	Slight to intermediate
Kharkof	1442	Resistant	Intermediate
Turkey	6175	Resistant	Intermediate
Ridit	6703	Resistant	Intermediate
Triplet	5408	Resistant	Intermediate
White Odessa	4655	Very resistant	Heavy (Fig. I, I, J)
		Emmer	
Emmer	4013	Extremely resistant	Very heavy (half to three-fourths)

ences in lignification probably would accomplish but little. It is believed that a direct measure of the force necessary to break the glumes from mature spikelets would be a better determination of shattering resistance.

A study of longitudinal sections from the more heavily lignified areas of susceptible and resistant varieties reveals some interesting differences. Sections K and L in Fig. 1 are from similar sections of the glumes of Sherman and White Odessa (C. I. 4655), respectively, in the early dough stage of maturity. The lignified band of the inner epidermis (dark area) of section K does not continue above the breaking point as prominently as it does in section L. This difference is shown more clearly by section A which is also from Sherman. The inner band of lignified tissue, as well as the lignified portion just beneath the outer epidermis in section L, is thicker than in section K. The continuity of the inner band of section A is not shown because that section was cut diagonally through this band.

Section N is from a section similar to that represented by L, except that it is from a mature glume of the same variety. By comparing section A with K and N with L it is apparent that the proportion of lignified tissue in the base of a glume in the early dough stage is practically the same as at maturity. Consequently, the material can be studied reliably in the dough stage, when it can be handled more conveniently than at maturity. The slightly greater intensity of lignification appearing in the sections from mature glumes is due to the fact that they are 20 microns thicker and consequently stain more heavily than those from immature glumes.

Section M illustrates an example of buckling of the outer epidermis at the breaking point which often occurs when the glume is forced outward by the enlarging kernel during the dough stages. This buckling was found to occur between the more heavily lignified ends (cross sectionally) in both susceptible and resistant varieties. Just how much effect it has upon resistance to shattering is not known. However, it seems reasonable to assume that the greater the buckling, the more easily the outer glume can be removed at maturity from the rachis of a given variety. If this is true, it offers an explanation of the fact that in a given head of wheat the outer glumes of a spikelet containing very plump kernels are often more easily removed than those of a spikelet with small kernels.

SUMMARY AND CONCLUSIONS

1. The breaking point of the outer glume of a wheat spikelet, when broken off, was between 0.1 and 0.2 mm above the inside base.

2. The proportion of lignified tissue in the base of the glume is practically the same in the early dough stage as at maturity.

3. The areas of greatest lignification were near the edges of the glume base. This is important because the edges are broken first when the glume is forced outward.

4. The varieties more resistant to shattering were found to have the greater proportion of lignified tissue at the breaking point of their outer glumes. Among varieties similar in shattering resistance differ-

ences in lignification could not be determined because of variability among individual glumes.

5. Longitudinal sections of the glume showed that the lignified band at the inner epidermis did not continue above the breaking point so prominently in varieties susceptible to shattering as in the resistant varieties.

6. The enlargement of the grain in a spikelet during the dough stages often causes a buckling at the breaking point of the outer epidermis of one or both glumes. This may explain the fact that in an individual wheat spike the outer glumes of spikelets containing very plump grains often are removed more easily than from spikelets with smaller kernels.

7. Although the measurement of lignification provides a better understanding of shattering, it is concluded that a direct measurement of the tenacity of mature glumes would be a better determination of shattering resistance.

MEASURING THE DIAMETER OF THE COTTON FIBER[1]

JERRY H. MOORE[2]

CERTAIN physical properties of the cotton fiber are of importance to cotton breeders and spinners. For many years length of staple has been considered one of the most important properties affecting the market and spinning value of cottons. In more recent years, strength, diameter, drag or clinging power, and unit fiber weight per inch have been measured in cotton varieties and their influence upon spinning quality noted.

In our American upland varieties of cotton, diameter of fiber is a property which appears to influence spinning value; that is, a smaller diameter is apparently associated with an increasing yarn strength. In an investigation of the relation of diameter and other physical properties of the cotton fiber to spinning value in seven American upland strains, Moore (6)[3] found that a decreasing fiber diameter was associated with an increasing yarn strength. In investigations of the spinning value of 14 samples of Egyptian cotton, Barritt (1) concluded, "that the selection of cotton for staple and low diameter would appear to offer everything the spinner can reasonably ask and all the grower can hope to supply."

The writer has noted during recent years that diameter is an inherited property, and other investigators state that this property depends mostly upon heredity. Different seasonal conditions may, of course, cause fluctuations in fiber diameter, but we can expect cottons differing significantly in fiber diameter to show these relative differences consistently in successive seasonal progenies. Since fiber diameter appears to be a fairly stable genetic property which can be selected and perpetuated and since it influences the spinning value of cottons it seems that breeders and other cotton investigators should select for this property in a program of cotton improvement.

Green, uncollapsed mature cotton fibers are tubular in form as shown by transverse sections in Fig. 1, B. Upon drying, however, such fibers assume irregular forms as indicated in Fig. 1, C. Measuring the diameter of the collapsed fibers is not very practicable, and the investigator could not always depend upon measurements of green material for the necessary data. The most practicable method of measuring fiber diameter consists of mercerization with a sodium hydroxide solution to restore the fiber to a roughly cylindrical form as illustrated in Fig. 1, A.

The object of this investigation is to note the relation of green, uncollapsed diameter to mercerized diameter and to make recommendations concerning the measurement of this property.

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[2]Cotton Technologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 609.

REVIEW OF LITERATURE

Calvert and Harland (3) thoroughly mercerized mature cotton fibers in an 18% solution of sodium hydroxide, then washed, dried, and mounted them in liquid paraffin on a slide, taking care to arrange the hairs approximately parallel. They then moved the slide across the microscopic field of view and drew a line across the middle of each fiber to indicate the width. Using a magnification of 1,200 diameters, they drew the lines with the aid of a *camera lucida* and measured

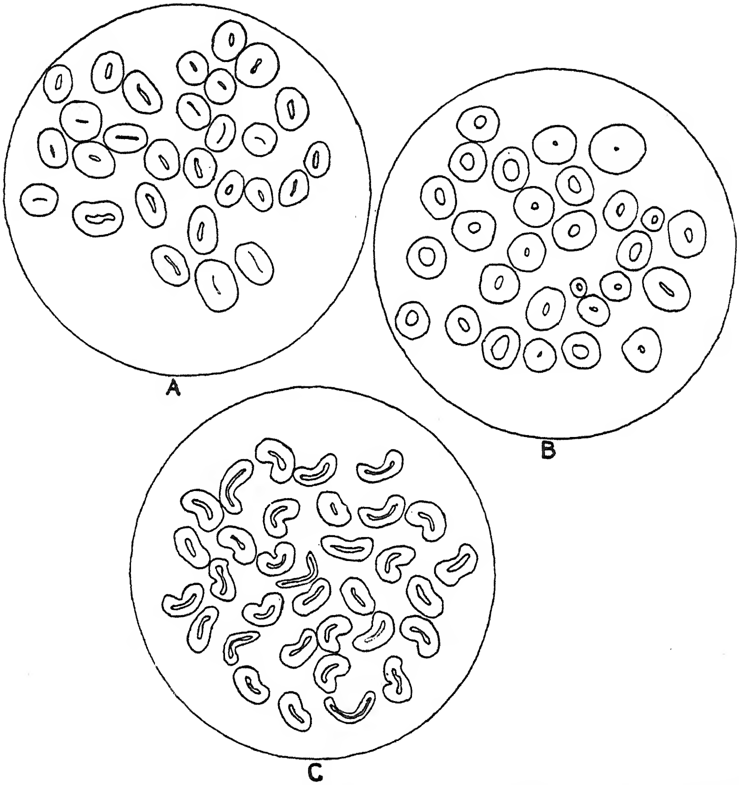

FIG. 1.—Outline drawings made from transverse sections of cotton fibers in an American upland variety. Magnified *220* X. A, mercerized, washed with water, and air-dried; B, green uncollapsed fibers 54 days of age from date when bloom appeared; C, collapsed, air-dried fibers.

them in millimeters. These investigators measured the mercerized diameter in 35 cottons covering a wide range and found the whole range of cottons to be comprised between the limits 11.9 and 20.2 microns, namely, between the finest Sea Island and coarse Peruvian.

Calvert and Summers (4) investigated the relation of the mercerized to the unmercerized hair width in 38 world cottons and found the ratio of the former to the latter to be approximately 0.8. They also noted the ratio of mercerized fiber width to uncollapsed fiber width in one Egyptian and one American strain of cotton and found the ratios to be, respectively, 0.72 and 0.62.[4]

[4]Ratios were calculated by the writer.

MATERIALS AND METHODS

Seven strains of American upland varieties (*Gossypium hirsutum* L) which had previously shown significant differences in fiber diameter were grown on the North Carolina State College farm during 1937 under similar environmental conditions.

Fresh blooms of each strain were tagged daily for several days with dated tags. When bolls from the dated flowers were just ready to open and 54 days old (from the date of blooming), they were picked, dissected, and then immediately put into a solution of 4 cc acetic acid, 8 cc formalin, and 82 cc of 70% ethyl alcohol to kill, fix, and preserve. Microscopic observation showed no apparent distortion of the pickled fibers. All the bolls preserved from the strains bloomed on the same day. Only one boll from a plant was placed in a jar, which was numbered to correspond with the plant number and name of strain. Eight to 10 bolls from as many plants of each strain were preserved for the observations.

In the laboratory, the green cotton fibers from a boll 54 days old were washed thoroughly in water to remove the fixative solution. Then approximately 100 uncollapsed fibers from this sample were taken at random under water and arranged approximately parallel on a wide slide. Water was added and a cover slip put on. Through the aid of a micro-projector apparatus and a mechanical stage, the diameter of the middle portion of each fiber was drawn by making a straight line as nearly as possible at right angles to the longitudinal boundaries of the fiber. Measurements have indicated that the width at the middle of the fiber length represents fairly accurately the average diameter of an entire fiber. By repeating this procedure a second lot of 100 fibers was measured in the boll sample, making a total of 200 measurements. A magnification of 380X was used in marking the diameter lines. The lines were measured to the nearest 0.5 mm with a millimeter rule. The average diameter of each sample was then calculated in millimeters and converted to the actual diameter in microns. The diameter of uncollapsed fibers was measured in three bolls from three plants of each cotton strain.

Some of the washed, uncollapsed fibers from each boll used above were exposed to the air at room temperature. Such exposure caused them to collapse and assume the morphological shape of normal field material. A composite sample was made from the collapsed fibers in the three bolls of each strain. Each composite sample was then mercerized thoroughly in an 18% solution of sodium hydroxide, washed thoroughly in water, and dried at room temperatures. One hundred fibers were then taken at random and mounted approximatey parallel to one another on a wide slide. Common mineral oil was added and a cover slip applied. Diameter measurements were then drawn and calculated as described in the preceding paragraph. A total of 400 measurements were made in each mercerized sample.

In order to obtain satisfactory transverse sections of cotton fibers with a minimum of distortion, the writer has tried several methods and over a period of 10 years has found the gelatin method to be the most satisfactory for general morphological outlines. This method has been previously described in its main details by Clegg and Harland

(5). The writer has used the method described by them with some modifications. A description of the method is given below.

Take a bundle of normal fibers, comb out the loose ones, pull and lap so as to have a bundle of several hundred fibers approximately parallel to one another. Cut a small window about ½ by ½ inch in a piece of cardboard about 1 by 1 inch. Cement the ends of the bundle on this cardboard with a fairly thin solution of collodion or any other cementing material which will not dissolve in water. A frame made from thin wood or wire is preferable to the cardboard frame. In some cases the ends of the fiber bundle may be held with a small paper clip at each end and the frame omitted. Carry the frame through alcohol to water in order to avoid air bubbles.

The material is next put in hot, concentrated gelatin (plain gelatin), which is kept hot for several hours at about 60° C. It is necessary to use gelatin in very high concentrations. When the frame is taken out of the solution there is a coating of gelatin surrounding the fibers. This is allowed to dry on the outside or immersed for a brief period in very cold water and the whole submerged in a solution of 95% ethyl alcohol and 5% commercial formaldehyde. The gelatin matrix can be built to the desired size by repeated dipping in the gelatin solution if the matrix is partially hardened in the formaldehyde-alcohol solution before each dipping. The material is hardened for 12 to 24 hours in the formaldehyde-alcohol solution and then the frame is cut and removed leaving the fibers in a hardened matrix which is transferred for final hardening to absolute ethyl alcohol or butyl alcohol for a period of 12 to 24 hours.

If the gelatin matrix has been built up to a large enough size, the cotton hairs are ready for sectioning. If the matrix surrounding the fibers is quite small, then it should be imbedded in paraffin which will act as a necessary support in cutting the hairs, which is done with a sliding microtome. During the sectioning process, it is necessary to have the edge of the long, very sharp knife set almost parallel with the matrix block in order to obtain a long, gradual cutting stroke, and the vertical angle of the knife should be about 15°. During the process the material is softened with 95% ethyl alcohol if too hard. If the gelatin is not excessively hard, the sections may be cut without wetting. In some cases sections can be cut to 5 μ in thickness, but usually it is preferable to limit the thickness to a minimum of 10 μ. The gelatin sections are unrolled in water on a glass slide, the water is allowed to evaporate, a drop of glycerine jelly added, and a cover slip applied.

The writer has easily obtained large gelatin blocks containing the cotton hairs in the following manner: Allow the first coat of gelatin covering the bundle of hairs to harden in the cold air. Place this matrix in a small paper cylinder about ½ inch in diameter and 1½ inches long, open at the top and closed at the bottom. Pour hot, concentrated gelatin into the cylinder, orient the matrix within, cool, and harden in the usual way. The paper may then be removed with the fingers and a sharp knife.

Green, uncollapsed fibers are carried from the fixative through water to gelatin, and thereafter the procedure is exactly like that followed in imbedding normal, collapsed hairs. Washed and dried, mercerized hairs are prepared for cutting according to the method just described for normal hairs.

EXPERIMENTAL RESULTS

The diameter of the uncollapsed fibers and its relation to that of the air-dried, mercerized fibers are contained in Table 1. The simple

correlation of uncollapsed diameter with mercerized diameter amounts to 0.95, which is very significant and quite satisfactory. It is likely that a substantial increase in the number of observations would give a correlation value somewhat nearer 1.00. The ratio of mercerized diameter to uncollapsed diameter in the seven strains is fairly uniform, the lowest being 0.623 and the highest 0.665, while the average ratio is 0.643. Thus, the close relationship of uncollapsed diameter with mercerized diameter, as shown in Table 1, indicates that the investigator can safely use the mercerized diameter for obtaining relative diameter differences in cotton varieties.

TABLE 1.—*The relation of mercerized, water-washed, air-dried fiber diameter to the diameter of uncollapsed, green fibers in seven strains of American upland cotton (crop of 1937).*

Cotton strains	Fiber diameter in microns		Ratio of mercerized to uncollapsed fiber diameter	No. of plants and bolls observed in each strain*	No. of diameter measurements	
	Mercerized fibers*	Uncollapsed fibers*			Mercerized fibers	Uncollapsed fibers
Acala 4067..........	14.47	23.22	0.623	3	400	600
Coker–Cleveland 884–4.............	15.03	23.18	0.648	3	400	600
Mexican 128.........	15.31	24.46	0.626	3	400	600
Rowden 40..........	15.84	25.00	0.634	3	400	600
Rowden 2088........	16.24	25.42	0.639	3	400	600
Mexican 87–8........	17.11	25.75	0.665	3	400	600
Farm Relief No. 1....	17.20	26.09	0.659	3	400	600
Average...........	15.886	24.731	0.643			

Correlation of mercerized with uncollapsed fiber diameter = 0.95 (highly significant)

*The diameter values probably do not accurately represent the actual values for the seven strains since only three plants were observed in each strain.

Transverse sections of normal, uncollapsed, and mercerized cotton hairs were cut in gelatin and their outlines drawn with the aid of a micro-projector. The drawings are shown in Fig. 1. Observation of the figure shows that the uncollapsed, green sections are approximately circular and that the mercerized sections are somewhat less circular. Sections of normal, collapsed hairs are, however, usually very irregular in general outline, which seldom shows much resemblance to the circular form of the uncollapsed fibers in the cotton boll. The contrast indicates the difficulty of measuring the true diameter from normal, collapsed hairs.

Barritt (2) describes a method for measuring the diameter of collapsed hairs. By his method width and thickness of the hair are measured from a longitudianl view and the sum of the two measurements is divided by two to obtain the approximate diameter. The writer has tried this method and has found considerable error involved. The measurements are also doubled. The writer also made perimeter measurements with the aid of a planimeter or dividers on

transverse sections of normal, collapsed hairs, and using the formula Perimeter/3.1416, calculated the diameter. Such measurements are very tedious and subject to considerable error. The writer has obtained satisfactory and consistent results for a period of 10 years by measuring either the uncollapsed diameter or the mercerized diameter, and has obtained relatively accurate data with a minimum of trouble.

SUMMARY AND CONCLUSIONS

The diameter of uncollapsed and mercerized fibers was measured in seven strains of American upland cotton and the correlation values and ratios calculated.

Methods are described for measuring the uncollapsed and mercerized fiber diameter. The gelatin method of sectioning cotton fibers is described and transverse sections of uncollapsed, normal collapsed, and mercerized fibers are shown.

The correlation of uncollapsed with mercerized diameter amounted to the very significant value of 0.95, the ratio of mercerized to uncollapsed diameter in the seven cotton strains ranged from 0.623 to 0.665, and the average ratio was 0.643.

The diameter of cotton fibers can be measured most easily in uncollapsed material or in mercerized samples. The cotton breeder can determine the fiber diameter of cotton strains or individual plants by using bolls just before they open or bolls about 29 days of age from the date of blooming. Material from earlier boll stages may be used, but the fibers from the younger bolls are rather delicate and hard to arrange on the slide. For general use in diameter measurements, the diameter can be most practicably determined in mercerized samples. Usually 200 preliminary observations in each mercerized sample will be sufficient to show a significant difference of about 0.75μ, and indicated differences in diameter of the promising strains can be checked by making 200 additional observations in each cotton strain. The standard error and the analysis of variance are useful in estimating the significance of differences in this property, but they are certainly not infallible and the investigator should depend to a considerable extent upon observation and experience when interpreting the results.

LITERATURE CITED

1. BARRITT, N. W. The intrinsic strength of cotton. Jour. Text. Inst., 20: T 70-T 74. 1929.
2. ————. The determination of fineness of Egyptian cotton and its relation to quality. Emp. Cotton Grow. Rev., 7: 19–29. 1930.
3. CALVERT, MARY, and HARLAND, S. C. The measurable characters of raw cotton. Jour. Text. Inst., 15: T 8-T 9, 1924.
4. ———— and SUMMERS, FREDERICK. The swelling of raw cotton hairs during mercerization without tension. Jour. Text. Inst., 16: T 233-T 268. 1925.
5. CLEGG, GLADYS, and HARLAND, S. C. The measurable characters of raw cotton. Jour. Text. Inst., 14: T 489. 1923.
6. MOORE, JERRY H. The relation of certain physical fiber properties in improved cotton varieties to spinning quality. N. C. Agr. Exp. Sta. Tech Bul. 58. (In press.)

RELATION OF SOME PLANT CHARACTERS TO YIELD IN WINTER WHEAT[1]

H. H. LAUDE[2]

THE relation of plant characters to yield in winter wheat might be considered from the viewpoint of the relation of characters to the maximum yield, that is, to yield under optimum conditions. Probably certain plant characters are related to the potential capacity of a variety to yield or to produce grain, e.g., varieties of wheat that require a long season in which to mature probably have a higher potential possibility for yield than those that mature in a short time. Also the potential capacity to produce grain may be greater for tall than for short varieties, for plants with wide leaves than for those with narrow leaves, etc.

Another view of the question is the relation of changes in plant characters corresponding to differences in yield of a crop such as wheat when it is grown in sub-optimal conditions. This approach has much greater practical and probably greater technical importance than the former since nearly all, if not all, wheat is grown in sub-optimal environment. The chief problem is the manner in which the plant adjusts itself to the more or less unfavorable conditions in which it is growing and its capacity to survive adversity.

It is believed to be axiomatic that a plant always does the best that is possible with the conditions that surround it. Also it may be considered that the protoplasm is a sensitive measure of environmental conditions. The yield of the crop may be looked upon then as an exact measure or a final integration of all ecological conditions that have prevailed throughout the life of the plant.

Under the influence of the particular ecological conditions surrounding the plant, its physiological activity is modified so as best to meet those conditions. In some cases the rate of leaf growth may be retarded, in others the extent of tillering may be reduced, in still others the size of the head may be limited, again fertilization of the florets may be interferred with or perhaps the amount of translocation to the seed may be limited.

Numerous ecological factors might be mentioned as possible causes for the modification of physiological activity which in turn may result in a modification of some morphological feature of the plant. On the assumption that yield is a measure of all ecological conditions and that these conditions modify morphological features of the plant, it appears reasonable to assume that relationships may exist between morphological features and yield. Evidently these relationships cannot be simple since there are numerous ecological factors involved and their effects upon the plant may be expressed in many ways. The environmental factors may exert an influence on stand, on rate of growth, time of tillering, extent of tillering, time of heading, num-

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ber of heads per plant or per area, weight of grain per head, number of kernels per head, time of ripening, height of plant, test weight, weight per 1,000 kernels, or the ecological condition may be expressed in winter injury, leaf rust, stem rust, loose smut, bunt, septoria or other diseases, in damage by Hessian fly, chinch bugs, or other insects, in drought injury, and perhaps in other ways.

Although these and perhaps many other ecological factors have a definite influence on the physiological activity of the plant, their relative importance varies greatly from field to field, from year to year, and among varieties. The complexity of the problem of measuring the specific effect of ecological factors is at once apparent. Ultimately such effects should be measured, that is, it should be known how much reduction in yield need be expected due to a certain degree of winter injury, how much due to a given amount of Hessian fly damage, how much to a moderate infection of leaf rust, etc. It is desirable to know also what yield can be expected in a certain field if the number of heads per plant is low, or medium, or high, or how the yield will be influenced if soil moisture is insufficient, say from March 10 to April 20, and many other similar questions.

As a preliminary plan it seems desirable to simplify the problem and determine first whether certain morphological effects are related to yield and if so with what degree of regularity. It appears logical to assume that yield is the function of (a) the number of plants per acre, (b) the number of heads per plant, (c) the number of kernels per head, and (d) the size of the kernel. An increase in any one or more of these without a corresponding decrease in one or more of them will result in an increased yield.

The time at which an ecological condition prevails or the nature of that condition may determine which of the four factors for yield will be affected, e.g., drought very early in the spring may influence tillering and reduce the number of heads, but drought shortly before harvest can influence only the size of the kernel. Bunt exerts its influence on yield primarily through the effect on number of heads, whereas stem rust affects yield chiefly through its influence on the size of the kernel.

With respect to varieties it has been observed that, in general, ecological conditions which favor high yield of one adapted variety will also favor high yields in other adapted varieties. It is evident that varieties differ as to their normal tillering, size of head, and size of kernel as well as other characters but many of the ecological conditions which tend to modify such characters in one variety will have a similar effect in other varieties. With respect to certain causes, however, varietal response may be greatly different. A familiar example is stem rust which may cause a low yield or the failure of a susceptible variety but have little effect on the yield of a highly resistant variety.

The general ecological conditions affecting wheat may be designated as those of season and those of location. Limited study of these indicates that seasonal conditions ordinarily establish a general pattern of plant growth, development, and yield. In any given season, however, wide variations in yield and plant characters often occur as a result of differences in the ecological conditions of different locations.

The relations between plant characters and yield are more apparent when the ecological conditions differ widely enough to induce large or moderately large differences in yield for then the differences in corresponding plant characters also tend to be large. Often in replicated varietal experiments the ecological conditions in the various replicates are so nearly alike as to cause little, if any, more fluctuation in yield and in most of the associated plant characters than is accounted for by experimental error, thus the "within variety" relationships of plant characters with yield are difficult to measure.

Data which are obtained from a wider range of ecological conditions within each year would appear desirable, at least for a preliminary study of the relation between plant characters and yield. An experiment which provides such data is being made at the Kansas Agricultural Experiment Station where since 1932 wheat has been seeded at intervals throughout the fall, the number of dates of planting being five in 1936, six in 1932, eight in 1935, and seven in each of the other three years. Thus in each year wheat has been grown in from five to eight more or less distinct ecological conditions. The varieties used in these experiments responded similarly to ecological conditions and therefore the average data for the four varieties are presented.

The data taken include yield, number of heads per acre, and bushel weight of wheat grown in each of the ecological conditions from 1932 to 1937 and weight per 1,000 kernels from 1934 to 1937. The relationships among the several characters and yield are shown graphically in Fig. 1. The different environments are represented at intervals from left to right across the graph in order of decreasing yield. Thus what presumably was the best condition is indicated at the left and the poorest at the right. The yield (Y) for each environment is indicated at points connected by the solid line, the number of heads (H) by the long dash, and the bushel weight (T) or kernel weight (K) by the short dash. The number of heads are reported as 1/10,000 the estimated number per acre, bushel weight as pounds per measured bushel, kernel weight as grams per 1,000 kernels, and yield as bushels per acre.

In 1932 there was a general relation between the number of heads and yield, and except in one case, a decrease in yield was associated with a decrease in test weight.

The best three ecological conditions in 1933 when the yields were about 45 bushels indicate an inverse relation for both number of heads and test weight when compared with yield. With lower yields there was a corresponding decrease in both of the other characters.

A positive correlation between kernel weight and test weight often has been observed and is believed to be general. The graph for 1934 includes weight per 1,000 kernels instead of test weight as for the previous years. A nearly constant relation was observed between the number of heads per acre and weight of the kernels on one hand and yield on the other, in fact the discrepencies probably do not exceed the experimental error.

In 1935 the close relation was found between kernel weight and yield, in fact every change in yield was associated with a similar change in weight of kernels. The lack of relation of number of heads

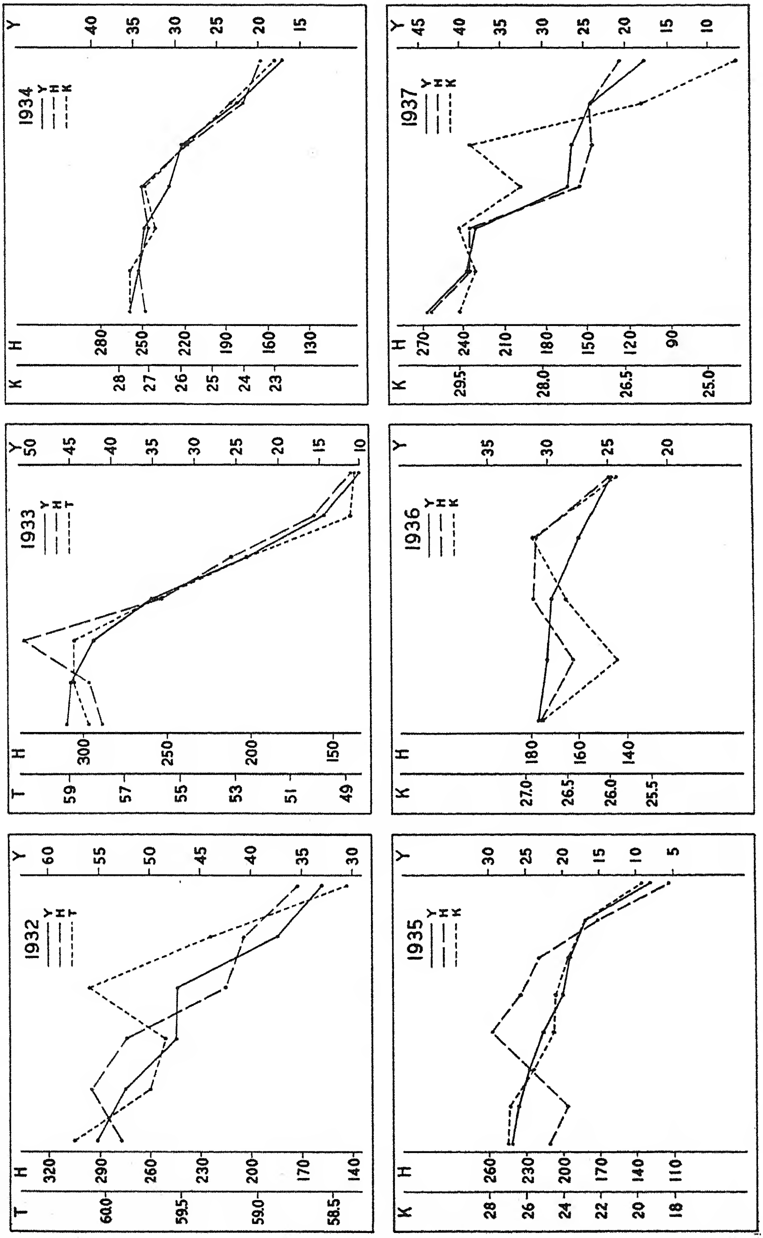

FIG. 1.—Relation between yield (Y), number of heads per area (H), and test weight (T) or kernel weight (K) of wheat grown in different ecological conditions at Manhattan, Kansas, 1932 to 1937. The best ecological condition indicated by the highest yield, is shown at the left and the poorest at the right of each graph.

compared with the previous years may have been due to the prolonged April and early May drought of that year. Such a disturbance at that time in the season may also account for the very close relationship between size of kernel and yield since the yield apparently was determined largely by the capacity of the plant to manufacture materials and translocate them into the existing kernels during the favorable weather which occurred late in the season.

The results for five ecological conditions studied in 1936 indicate that some other factor or factors than number of heads and size of kernel were important in influencing the yield of wheat. This suggests the need for complete data regarding the crop and conditions affecting it and also the importance of season variation which may bring different factors into important relation with yield.

In 1937 the relationship between number of heads and yield was much better than between size of kernel and yield. The importance of number of heads in relation to yield also was observed in that season within varieties in triplicate variety test plats.

It is fully realized that this limited interpretation of data is only preliminary and that detailed statistical treatment should be given the agronomic results. Even though it is shown, after further study, that a few simple measurements are related to yield, the question will not yet be answered but will only be opened for really intensive study. For it is perhaps more important to the development of science to know why the number of heads vary and what are the causes for differences in weight of kernels. The answer in general can now be stated, but can the cause in relation to yield or in terms of probable yield be interpreted? For example, What is the influence on yield of drought at a certain time in the life of the plant? What is the probable effect on yield of a moderate infection of leaf rust at a certain stage of the crop? Answers to these and many other questions await solution. It is not within the realm of this paper to go into that phase of the question, but rather to point out that it may be possible to make certain observations and measurements of the plant which have a probable relation to yield.

The highly variable climate of the hard winter wheat region adds to the difficulty of determining relations that are even moderately consistent from year to year. If the critical ecological condition strikes late in the life of the plant the effect must be different than if it occurs early in the season. The adverse condition at either time probably will reduce the yield, but if it comes near the time of maturity only the size of the kernel will be influenced whereas if the unfavorable condition occurs early in the spring the number of heads, the size of the head and perhaps also the size of the kernel may be affected. If the adverse condition prevails at seeding time the number of plants (stand) in addition to the other characters may be influenced.

Even with such highly variable conditions it appears that the expression of ecological factors upon the growth or character of the crop can be interpreted with some degree of reliability to indicate a probable yield.

A knowledge of how the plant is influenced by environmental conditions and of the relation of those influences to yield also will indicate

what genetic features need to be changed in order to improve the adaptation and yield of a variety. Furthermore, this information will point out how ecological conditions for the crop can be improved by tillage practices, fertilizer treatments, time and rate of seeding, etc.

In conclusion, may the suggestion be made that it appears important and decidedly worthwhile to learn whether and to what extent physical conditions of the environment affect the physiology of the plant so as to modify its morphology in a way that is related to yield.

RENOVATION AND ITS EFFECT ON THE POPULATIONS OF WEEDS IN PASTURES[1]

R. F. FUELLEMAN AND L. F. GRABER[2]

IN southwestern and western Wisconsin, over 45% of the land area is in permanent pasture. The dominant species is bluegrass (*Poa pratensis*). The topography is such that extensive utilization of the land for grazing has been required as a means of erosion control. Much credit is due the farmers of this region for their efforts in maintaining this far-sighted policy of soil conservation. But, as is so often true of grasslands, many of the permanent pastures of this region have suffered severe declines in productivity and quality within the last 10 years.

Numerous interacting factors are involved. It seems that the very attributes of such a biotic complex are either cumulatively destructive or cumulatively constructive. The middle ground does not seem to prevail for long. A waning fertility with 50 or more years of grazing without restoration of plant nutrients does not manifest its influence on the vegetation spontaneously, but it does ultimately. Add to it, the stress of several seasons of excessive heat and drought, the inevitable tendency for early and continuous close grazing with declines in the carrying capacity, and then, the cumulative nature of things destructive will manifest itself. It did in southwestern and western Wisconsin as it has done elsewhere. The interacting conditions like these thinned the bluegrass sods and widely extended the egg-laying areas of the June beetle (*Phyllophaga* sp.). Enormous populations developed in 1929, 1932, and 1935, and the wholesale injury of the grass covering by the larvae (white grubs) was very severe. Then followed weeds—ragweeds, horseweeds, and many others which could easily compete with grass, beleagured by heat, drought, overgrazing, and grubs.

RENOVATION

A plan of pasture improvement with attributes that were cumulatively constructive over a period of years was needed to meet such a drastic situation. Such a plan was attained, to a marked degree, in the practices of pasture renovation. The method[3] of establishing deep-rooted dry-weather legumes, alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba* or *officinalis*), and red clover (*Trifolium pratense*), in permanent but thin grass sods without plowing, have reached the status of substantiated farm practice in many regions.

Unlike plowing, the scarification of grass sods with a disk or spring tooth harrow maintains, to a high degree, the binding power of the grass roots; and with the broken sods remaining on the surface, it is

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[3]GRABER, L. F. Renovating bluegrass pastures. Circ. 277, Col. of Agr., Univ. Wis. 1936.

possible to establish productive and drought-enduring legumes on steep slopes with a minimum danger of erosion. Moreover, renovation has effectively controlled the injury of white grubs. It has induced much-needed liming and fertilization of pastures with phosphates and potash. It has reduced drought hazards and has enhanced fertility by virtue of the associated growth of leguminous plants with grasses. And with all these cumulative merits, it has greatly reduced the prevalence of undesirable species, particularly, unpalatable weeds. It is the purpose of this paper to show how effectively weed control has been accomplished after the dry-weather legumes were established in permanent pastures.

PROCEDURE

In 1934 and 1935 portions of from 2 to several acres of 30 widely distributed permanent pastures were renovated. As reported by Fuelleman and Graber,[4] such renovations almost completely eliminated subsequent injury to the grass by white grubs, reducing their populations from 91 to 98% when compared with the populations which prevailed in the adjacent non-renovated portions of these widely distributed pastures.

During the summer of 1937 weed counts were made on 27 of these renovated areas and on 27 adjacent areas not renovated. Weed counts were also made in 3 additional pastures where portions had been renovated, thus providing 30 pastures for the weed study.

In this weed survey, a quadrat having an enclosed area of 1/20,000 acre was used. The pasture under scrutiny was examined and the vegetational trends noted. It was found in most cases a diagonal course across the area gave a better picture of the weed population. The quadrat was thrown at random, the distance between throws being equalized by pacing and avoiding, in so far as possible, obstacles such as gulleys, old fence rows, etc. The species and number of weeds were noted and recorded upon suitable charts. Each species was recorded by number (Table 1). A total of 10 samples was taken from each of the renovated and non-renovated portions of the pastures. In all cases the portions of the non-renovated pastures used for making sample counts were approximately of the same size as the portion renovated.

CHARACTER OF WEED GROWTH

The plants which were regarded as weeds are given in Table 3. Most of them were annuals. Ragweeds (*Ambrosia artemisiifolia*) and horseweeds (*Erigeron canadensis*) were most generally prevalent. In the non-renovated portion, where weeds were most abundant, ragweeds represented the highest percentage of the total weed population in 15 pastures, horseweeds in 13 pastures, mock pennyroyal (*Hedeoma hispida*) in 1 pasture, and catsfoot (*Antennaria compestris*) in 1 pasture. Other weeds which constituted from 20% to 36% of the total weed population s and could be regarded as prominent sub-dominants in the non-renovated bluegrass were mock pennyroyal in 5 pastures, red sorrel (*Rumex acetesolla*) in 1 pasture, yarrow (*Achillea millefolium*) in 1 pasture, sandwort (*Sabulina sp.*) in 1

[4]FUELLEMAN, R. F., and GRABER, L. F. Pasture renovation in relation to populations of white grubs. Jour. Amer. Soc. Agron., 29: 186–196. 1937.

TABLE 1.—*Weed species found in unrenovated and renovated portions of 30 pastures.*

Weed No.	Scientific name	Common name
1	*Lychnis alba*	White campion
2	*Rumex crispus*	Curled dock
3	*Erigeron canadensis*	Horseweed
4	*Ranunculus acris*	Tall buttercup
5	*Viola pedatifolia*	Yellow violet
6	*Achillea millefolium*	Yarrow
7	*Ambrosia artemisiifolia*	Ragweed
8	*Taraxicum officinale*	Dandelion
9	*Potentilla monspeliensis*	Cinquefoil
10	*Erigeron ramosus*	Daisy fleabane
11	*Silene noctiflora*	Sticky catchfly
12	*Thlaspi arvense*	Pennycress
13	*Veronica peregrina*	Speedwell
14	*Lepidium apetalum*	Small peppergrass
15	*Lepidium campestre*	Tall peppergrass
16	*Rumex acetosella*	Red sorrel
17	*Chenipodium alba*	Lambs quarter
18	*Amaranthus retroflexus*	Pigweed
19	*Polygonum aviculare*	Knotweed
20	*Chrysanthemum Leucanthium*	Oxeye daisy
21	*Hedeoma hispida*	Mock pennyroyal
22	*Silene anthirrhina*	Large chickweed
23	*Specularia perfoliata*	Venus looking glass
24	*Bursa pastoris*	Shepard's purse
25	*Polygonum convulvulus*	Black bindweed
26	*Oxalis violacea*	Small sorrel
27	*Asclepias syriaca*	Common milkweed
28	*Verbena hastata*	Smooth vervain
29	*Polygonum hydropiper*	Smartweed
30	*Polygonum Persicaria*	Lady's thumb
31	*Verbena stricta*	Hoary vervain
32	*Chamaesyce maculata*	Spotted or creeping spurge
33	*Agropyron repens*	Quack grass
34	*Panicum capillare*	Witch grass
35	*Linaria vulgaris*	Toad flax
36	*Verbascum thapsus*	Mullen
37	*Antennaria campestris*	Catsfoot
38	*Sabulina* sp.	Sandwort
39	*Setaria* spp.	Foxtails, green and yellow
40	*Cirscium arvense*	Canada thistle
41	*Plantago majus*	Plantain
42	*Erigeron annus*	Field daisy
43	*Euphorbia peplus*	Flowering spurge
44	*Physalis lobata*	Ground cherry
45	*Cerastium vulgatum*	Mouse-eared chickweed
46	*Nepata cataria*	Catnip
47	*Cirscium lanceolatum*	Bull thistle

pasture, lady's thumb (*Polygonum persicaria*) in 1 pasture, catsfoot (*Antennaria compestria*) in 2 pastures, and spotted spurge (*Chamasyce maculata*) in 1 pasture.

WEEDS AS INDICATORS OF PASTURE IMPROVEMENT

It is well recognized that the prevalence of undesirable species in a pasture is indicative of the productivity of the desirable species.

An abundance of annual and biennial weeds in grasslands is generally a result of a reduction in the competitive efficiency of desirable grasses and legumes. This may result from improper grazing, from deficiences in fertility, from excessive heat and drought, from grub injury, or from other broad limitations of this nature. Given a favorable environment and proper grazing management, there are few annual and biennial weeds which can long compete with desirable grasses and particularly is this true of pastures where bluegrass is dominant in southwestern and western Wisconsin. Even perennials do not make great progress in their spread if the density of the sod is maintained and the regenerative activity of desirable grasses is kept at a high and productive level. We may, therefore, regard the weed population data obtained in this study as a rough and partial measure of the degree of pasture improvement by renovation methods.

WEED POPULATIONS REDUCED BY RENOVATION

The season of 1937 was of a character to encourage an abundance of summer weeds in permanent pastures of western and southwestern Wisconsin. Ample moisture prevailed in the forepart of the season, but it was followed with severe drought and heat in July and August and early September, thus favoring the growth of many resistant species but particularly ragweeds and horseweeds.

The effect of renovation under such conditions on the total weed populations of 30 widely distributed pastures is shown in Fig. 1 and Table 2. Elimination was not complete, but the reduction as a result of renovation are very marked. In the portions of 27 pastures renovated in 1934 and 1935, weeds were 85.7% less in numbers than on the adjacent areas not renovated. When it is considered that weeds in the non-renovated areas of these 27 pastures were prevalent at the average of nearly 1 million per acre (varying from 412,000 to 1,876,000), such reductions are very substantial. Renovation of a portion of one pasture in 1936 reduced the population of weeds in 1937 by 73.0% and with another renovation in 1935 the reduction in weed populations in 1937 was 91.0%.

TABLE 2.—*Number of grubs per acre in 1936 and the number of weeds per acre in 1937 on adjacent non-renovated and renovated portions of 30 widely distributed permanent bluegrass pastures in western and southwestern Wisconsin.*

No. of pastures on which determinations were made	Year portions of pastures were renovated	Average no. of grubs per acre in 1936		Average no. of weeds per acre in 1937		
		Portion not renovated	Portion renovated	Portion not renovated	Portion renovated	% reduction
15	1934	133,580	1,636	937,067	132,667	85.8
12	1935	165,552	15,241	1,019,833	146,167	85.7
1	1929	117,612	23,950	2,554,000	162,000	93.6
1	1935	———	———	1,004,000	90,000	91.0
1	1936	———	———	808,000	218,000	73.0

Of particular interest is the renovation of 4 acres of a large pasture in 1929. This area (Table 2) had passed through three heavy flights of egg-laying June beetles (*Phyllophaga sp.*) without sufficient egg-depositions to exhibit a noticeable degree of white grub injury. Its condition in 1937 is well illustrated by a weed population of 162,000 per acre compared with 2,554,000 per acre in the adjacent pasture area of 4 acres which had never been renovated. It so happens that this is the oldest outlying renovation area in Wisconsin. The soil was

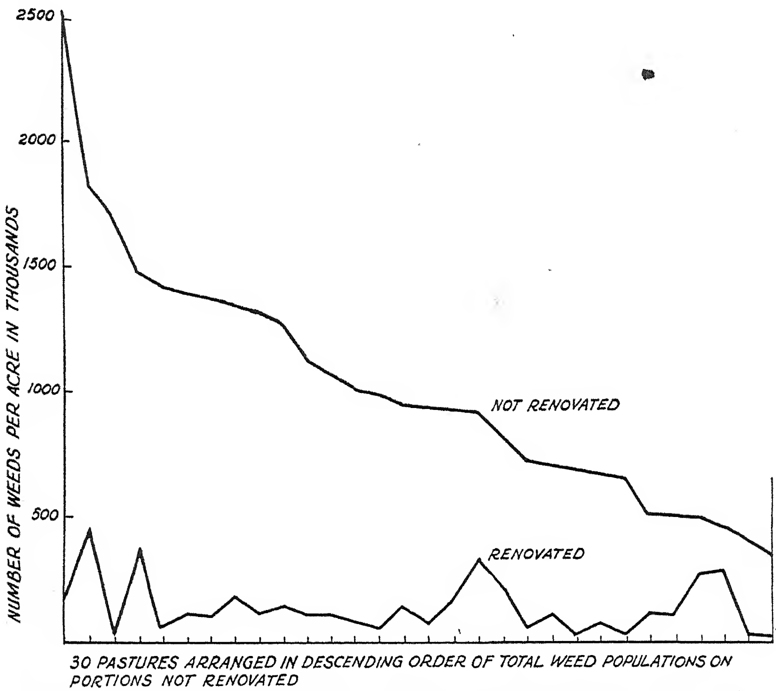

FIG. 1.—A comparison of the total number of weeds per acre in 1937 on the renovated and non-renovated portions of each of 30 widely distributed bluegrass pastures in western and southwestern Wisconsin. The pastures are arranged in the descending order of the number of weeds per acre on the non-renovated portions.

very low in fertility and ample lime and superphosphate were applied in 1928 to the 4-acre area which was to be renovated with biennial white blossomed sweet clover. An excellent stand was obtained in 1929 and by means of grazing management this leguminous plant has regularly re-established itself by self-seeding for the past 7 years, including 1937. It is now and has been a clear-cut demonstration of the lasting and residual improvement which prevails with the practices involved in successful renovation.

The populations of horseweeds and ragweeds were very effectively controlled by renovation. In 30 pastures where ragweeds prevailed at the average rate of 423,200 per acre in the non-renovated portions,

renovation reduced them to 60,400, or 85.7%. In 30 pastures where horseweeds prevailed at the average rate of 336,267 per acre in the non-renovated portions, renovation reduced them to 26,600 per acre, or 92.1%.

PREVALENCE OF RAGWEEDS AND HORSEWEEDS NEGATIVELY CORRELATED

In the non-renovated areas of the 30 pastures an abundance of ragweeds (*Ambrosia artemisiifolia*) was associated with a reduced number or the absence of horseweeds (*Erigeron canadensis*), as shown in Table 3 and Fig. 2. The negative correlation coefficient between the percentages of the total weed populations consisting of ragweeds and of horseweeds is –.78. This shows that, in general, a high percentage of one of these two weeds in the non-renovated pastures was correlated with a low percentage of the other. In the non-renovated areas where both ragweeds and horseweeds prevailed, the two species did not grow very generally in association with each other, but

TABLE 3.—*Total number of ragweeds and of horseweeds per acre and the percentages of the total number of weeds per acre consisting of ragweeds and of horseweeds in each of the unrenovated portions of 30 pastures in western and southwestern Wisconsin.*

Pasture No.	Total no. of weeds per acre (000) omitted	Ragweeds		Horseweeds	
		No. (000) omitted	%	No. (000) omitted	%
25	358	354	98.9	0	0.0
34	2,554	2,260	88.5	4	0.2
8	512	438	85.5	10	1.9
3	506	408	80.6	0	0.0
21	1,264	958	75.8	176	13.9
14	932	636	68.2	102	10.9
10	1,478	946	64.0	228	15.4
23	652	398	61.0	154	23.6
20	928	512	55.2	12	1.3
6	716	386	53.9	26	3.6
31	808	398	49.3	58	7.2
15	1,118	486	43.5	360	32.2
7	994	402	40.4	274	27.6
12	702	280	39.9	162	23.1
29	1,394	554	39.7	440	31.6
9	1,332	514	38.6	654	49.1
2	1,062	394	37.1	516	48.6
5	1,316	460	34.9	498	37.8
28	1,408	404	28.7	652	46.3
27	1,750	460	26.3	898	51.3
4	930	210	22.6	74	7.9
1	674	148	21.9	288	42.7
16	1,876	372	19.8	944	50.3
24	472	94	19.9	212	44.9
19	510	76	14.9	98	19.2
13	412	56	13.6	100	24.3
26	692	40	5.8	320	46.2
22	934	44	4.7	598	64.0
11	1,372	8	0.6	1,362	99.3
33	1,004	0	0.0	872	86.9

rather the horseweeds tended to prevail in patches separate from the patches of ragweeds. Unfortunately, data were not collected to measure the degree of such dissociation in the growth of the two species within any given pasture nor has the nature of the apparent antagonism between them been ascertained.

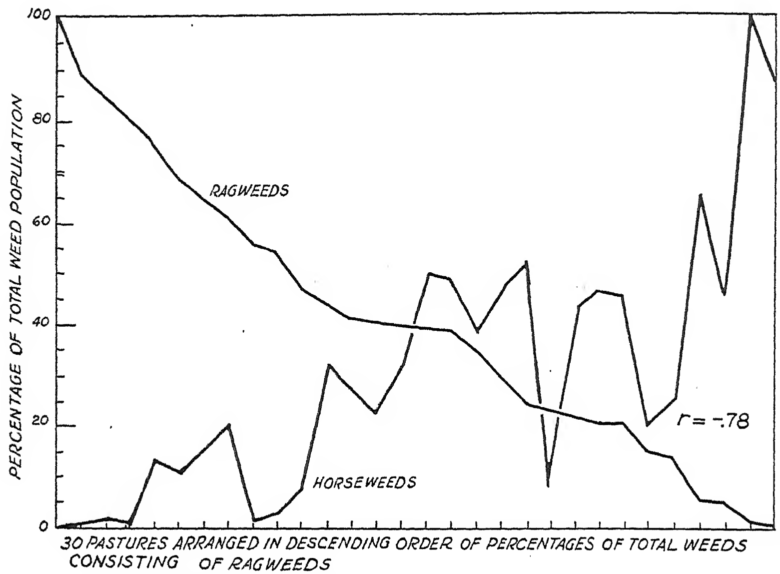

FIG. 2.—A comparison of the percentages of the total weed populations, consisting of ragweeds and horseweeds, on the non-renovated portions of 30 widely distributed bluegrass pastures of western and southwestern Wisconsin in 1937. The pastures are arranged in the descending order of the percentages of ragweeds to show the relationships with the percentages of horseweeds.

DISCUSSION

Since the data covers a period of one summer only, it is not feasible in this time-limited study to attempt to associate the weed growth in 1937 with specific factors. In outlying trials of this character the collection of data on causal factors was handicapped by a lack of adequate controls and supervision. Of course, it was true that the prevalence of white grubs in 1936 had, in a broad way, a very considerable influence on weed growth in 1937, but because of other factors involved the exact effect of previous grub injury of the grass sods on the subsequent weed growth is not ascertained. Likewise, the influence on weed growth of such practices as liming, fertilization, cultivation, and deferred grazing, which were necessary for the success of the renovations, is not determined nor is the influence of the legumes themselves. While the 30 non-renovated areas were grazed more or less uniformly, only 20 of the renovated areas were used solely for grazing, 6 were cut for hay and 4 were utilized for hay and pasturage. Such diversity of treatment of the renovated portions

did not seem to influence materially their total weed populations, but the means of actually measuring the effects it may have occasioned were not available. What was accomplished in these trials has been the determination of the gross effect of all such variable interacting factors on weed populations rather than a differentiation of the influence of any single factor.

SUMMARY

Renovation of permanent grasslands in Wisconsin is a method of pasture improvement involving the establishment of such dry-weather legumes as alfalfa (*Medicago sativa*), sweet clover (*Melilotus alba* and *officinalis*), and red clover (*Trifolium pratense*) in thinned pasture sods without plowing.

Portions of 30 widely distributed bluegrass pastures in western and southwestern Wisconsin were renovated in 1929, 1934, 1935, and 1936. In 1937, the populations of species regarded as weeds were determined in the renovated areas and in adjacent areas of equal size not renovated.

The 27 renovations of 1934 and 1935 reduced the total weed populations 85.7% in 1937, and likewise a reduction of 91.0% and 73.0% resulted from one renovation in 1935 and one in 1936, respectively. Nine years after the renovation of a 4-acre area of another pasture the total weed population was 93.6% less than that of the adjacent area of 4 acres not renovated.

Ragweeds (*Ambrosia artemisiifolia*) and horseweeds (*Erigeron canadensis*) were the most generally prevalent species. In 30 pastures, renovation reduced ragweeds 85.7% and similarly horseweeds were reduced 92.1%.

Where high percentages of the total weed populations of the non-renovated portions of the 30 pastures consisted of ragweeds, the percentages of horseweeds were low and the negative correlation coefficient between such percentages was –.78.

TREND STUDIES IN RELATION TO THE ANALYSIS OF YIELD DATA FROM ROTATION EXPERIMENTS[1]

K. H. W. KLAGES[2]

THE usual method of analysis of yield data from rotation experiments is based strictly on a presentation of the average yields obtained. While average yields are indispensable to any presentation of results from rotation and other field plat experiments in general and offer the best direct basis of comparison of various plat treatments, they may nevertheless be supplemented to advantage by additional criteria, such as evaluation of trend relationships and expressions of seasonal variability. The writer found in presenting the results of rotation experiments to groups of producers that as much, if not more, interest was shown by farmers in the trend relationships as in the average yields obtained from the various sequences of cropping. A graphical presentation of yield trends met with exceptionally good reception. The trend relationships were in all cases discussed in connection with the average yields obtained.

The above referred to producer response to trend relationships of crop rotation data provided the main impetus for presenting this type of analysis at this time.

MATERIALS AND METHODS

The yield data of 10 rotations conducted on the University Farm at Moscow, Idaho, were available for analysis. These rotation experiments were started in 1915 and have been carried up to date, making the yield data of a 23-year period available. Except in the case of the potato plats, the same varieties were used during the course of the experiment. Obviously, the substitution of varieties with differing yielding capacities may materially influence trend relationships. The varieties used were Red Russian winter wheat, Swedish Select oats, Alaska peas, Rustlers White Dent corn, and Early Ohio, Bliss Triumph, and Katahdin potatoes. These rotations, with their crops and practices in their order of sequence are presented in Table 1. It is not the object of this paper to discuss the relative merits of these various systems of cropping to Idaho conditions. The yield, trend, and variability data pertaining to them are given only for purposes of presenting a method of analysis.

LINEAR AND CURVILINEAR TRENDS

Yield data may be fitted to various types of curves depending on the particular types of trends shown and closeness of fit. For purposes of providing supplementary information to the interpretation of mean yields, straight line trends have several decided advantages over curvilinear trends.

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[1]Contribution from the Department of Agronomy, University of Idaho, Moscow, Idaho. Published with the approval of the Director as Research Paper No. 166 of the Idaho Agricultural Experiment Station. Received for publication March 31, 1938.

[2]Professor of Agronomy.

Straight line trends call for the calculation of but one variable to designate a uniform positive or negative slope of the trend line, while curvilinear trends demand the rather laborious calculation of two or more such variables. While straight line trends are not applicable to all compilations of yield data, they indicate the general or average trend of a yield test extending over a period of years in a direct and readily understandable manner. A producer contemplating a modification in his system of cropping has a right to inquire as to the trends that his yields may be expected to take by adapting a rotation recommended to him. Such a question is more readily and directly answered by information relating to trends of yields shown by experimental plats devoted to designated systems of cropping than by a mere recitation of averages. In such instances the average or straight line trend is especially useable. It is recognized, as will be brought out later, that the straight line analysis may not give all the available information regarding a trend relationship. It does, however, have the outstanding advantage of directness by providing a single figure characterizing the slope of the trend line which is easily comprehended by the layman with little knowledge and not infrequently less appreciation of higher mathematics.

THE STRAIGHT LINE TREND

The straight line trends presented were calculated by the method of least squares. The formula of the required line is $y=ax+b$.

The slope of the line "a" and the y-intercept "b" are determined from the observed pairs of values of x and y. The yield data are plotted by designating the successive years of the experiment by x values and placing them on the x axis. Since the graph starts at the point of origin the value of x for the initial year of the experiment is 0. The respective yields, the y values, for the successive years of the experiment are plotted on the y axis. When "a" and "b" are known, the value of y can be calculated for any selected value of x. With a calculating machine available the required calculations can be carried out with speed and precision.

The equation for the required line of least squares for the wheat yields in rotation 1 is found to be $y=1.26x+38.97$. Fig. 1 shows the seasonal yields of wheat in rotation 1 together with the straight line and parabola trends. It will be observed that the linear trend line shows, since the value of "a" is positive, a rise of 1.26 bushels per year. The y axis is intercepted at 38.97 bushels, that is at the calculated value of "b". The extremities of the straight line trend extend from 38.97 to 66.69 bushels for the values of x at 0 and 22, respectively.

In rotation 4 a positive trend is in evidence for the wheat, while the oats yields show a definite negative trend. The value of "a" for the equation of the line of least squares for the wheat yields is 0.63 with the extremities extending upward from 45.67 to 59.53 bushels. Since the equation of the linear trend line for the oats yields is $y=-0.52x+48.00$ the extremities of the line extend downward from 48.00 to 36.56 bushels for the values of x at 0 and 22, respectively, thus showing an average yearly decrease of 0.52 bushel per acre.

The trend relationships of the oats yields of rotation 4 are shown graphically in Fig. 2.

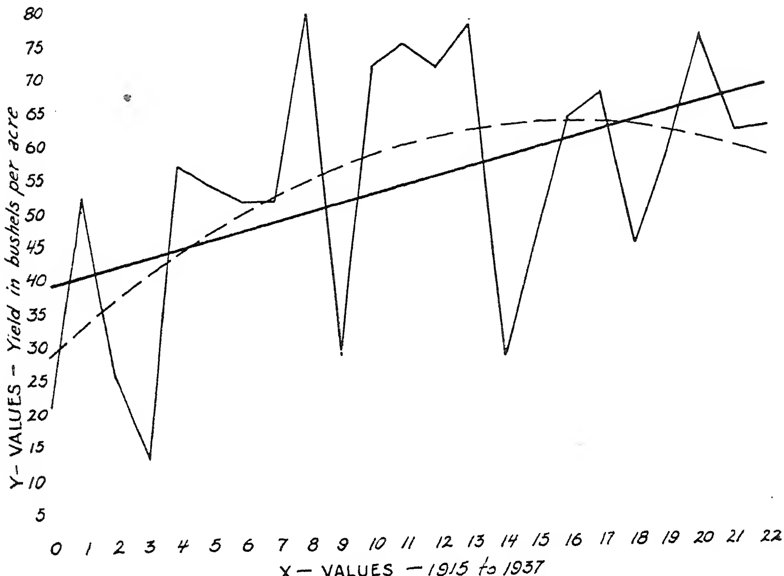

FIG. 1.—Straight line and parabola trends of the seasonal yields of wheat in rotation 1 from 1915 to 1937, inclusive.

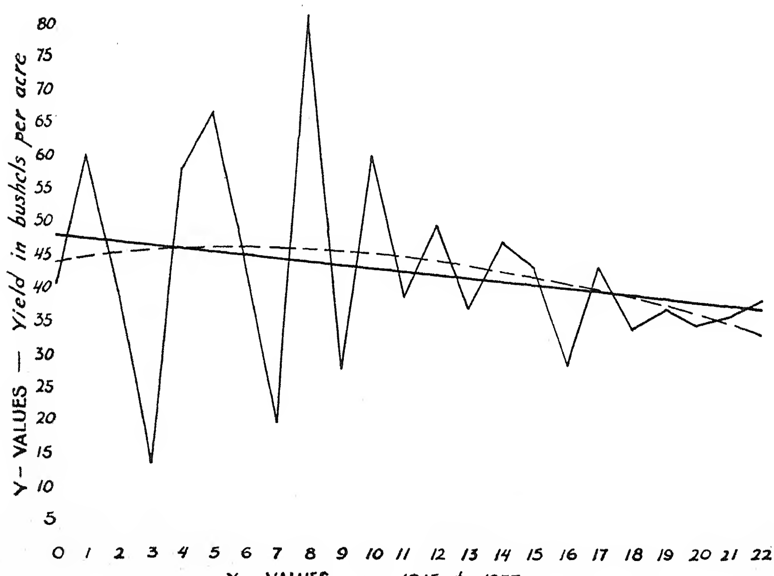

FIG. 2.—Straight line and parabola trends of the seasonal yields of oats in rotation 4 from 1915 to 1936, inclusive.

The above examples suffice to show the practical significance of straight line trends. Table 1 gives the average yields, yield trends, extremities of the trend lines for the course covered by the experiments, and the coefficients of variability of the seasonal yields for each of the crops of the 10 rotation systems previously referred to.

TABLE 1.—*Average yields, straight line trends, and variability in the seasonal yields of crops in rotations on the University Farm, Moscow, Idaho, for a 23-year period, 1915 to 1937, inclusive.*

Rotation No.	Crops and sequence	Average yield, bu.	Yield trend	Extremities of trend lines	Coef. of variability of seasonal yields
1	Wheat	52.9	+1.26	38.97–66.69	36.00±4.05
	Oats	63.5	+1.26	49.60–77.32	35.79±4.03
	Peas plus manure	20.0	–0.51	25.15–14.95	43.31±5.34
2	Wheat	43.0	+0.47	37.82–48.16	31.47±3.48
	Oats	47.1	+0.20	44.96–49.36	33.43±3.70
	Peas	20.3	–0.42	24.50–16.10	40.72±4.93
3	Wheat	56.4	+0.96	45.86–66.98	30.99±3.40
	Oats	56.1	+0.46	51.04–61.16	40.50±4.68
	Fallow plus manure	——	——	—— ——	—— ——
4	Wheat	52.5	+0.63	45.67–59.53	25.28±2.69
	Oats	42.3	–0.52	48.00–36.56	35.54±4.00
	Fallow	——	——	—— ——	—— ——
5	Wheat	50.0	+1.18	37.03–62.99	32.33±3.57
	Oats	59.7	+0.62	52.84–66.48	33.81±3.77
	Corn plus manure	7.82*	–0.11	8.96– 6.65	35.70±4.11
6	Wheat plus 200 lbs. $NaNO_3$	47.4	+0.10	46.27–48.47	25.08±2.67
	Oats	48.3	–0.67	55.65–40.91	40.46±4.68
	Potatoes, 1916–1922	120.7			
	Corn, 1923–1937	5.51*			
7	Wheat	34.3	+0.24	31.75–37.03	29.21±3.17
	Oats	42.4	–0.24	45.06–39.78	34.74±3.88
	Corn	5.61*	–0.12	6.87– 4.35	34.87±3.98
8	Wheat	49.2	+0.17	47.30–51.04	25.05±2.67
	Oats	47.1	–0.51	52.64–41.42	36.14±4.07
	Potatoes	84.5	–3.36	119.71–49.15	49.12±6.16
11	Continuous wheat plus manure:				
	Replication A	29.5	+0.15	27.84–31.14	44.61±5.29
	Replication B	35.9	–0.06	36.60–35.28	41.85±4.88
	Replication C	34.7	–0.002	34.71–34.67	35.50±4.00
	Average	33.4	+0.03		40.65
12	Continuous wheat:				
	Replication A	20.1	–0.15	21.76–18.46	44.60±5.29
	Replication B	24.1	–0.09	25.09–23.11	36.83±4.18
	Replication C	23.7	–0.28	26.75–20.59	37.40±4.25
	Average	22.6	–0.17		39.61

*Tons.

Since the respective equations for the trend lines can be readily constructed from the information given it is not necessary to take space to give them in Table 1.

The trend data here presented cannot be used for purposes of predicting the future yields of the plats on which they are based. It cannot be expected that the high upward, and in some instances downward, trends will continue at their past rates. Sooner or later a state of equilibrium will be reached in the yields of these crops. There is some evidence that this point has already been reached in the case of some of the rotations. More will be said about this point in the discussion of parabola trends. The exact position of this yield equilibrium will be determined by the climatic conditions under which the crops are grown and by the soil changes induced by the different systems of cropping. Progressive soil changes in turn can be expected to modify the response of the plants grown to the particular climatic features of their environment.

YIELD AND TREND RELATIONSHIPS

It will be observed from Table 1 that the high-yielding plats of winter wheat and oats in the various rotation systems generally also show relatively high upward trends, while the low-yielding plats show either low, or in some instances, definite negative yield trends. The higher yields and also the higher upward yield trends in the rotations to which manure is applied as compared with the lower and not infrequent negative trends of the rotations not receiving manure are especially noteworthy. Rotation 1 shows a wheat yield of 52.9 bushels and a positive trend of 1.26 bushels, while the wheat yields of the corresponding rotation 2, without applications of manure, shows a yield of only 43.0 with a trend of 0.47 bushel.

The differences in the oats yields and trends in rotations 1 and 2 are even more pronounced than for the wheat. The differences in the yields of the wheat and oats in rotations 3 and 4 become especially significant when they are considered in the light of their trend relationships. The differences in the yields and trends of the wheat following the fallow are not as outstanding as those of the second crop following the fallow, that is the oats. The beneficial effects of the fallow are apparently taken up completely, or nearly so, by the wheat without any significant carry-over effect to the oats crops.

With the applications of manure the oats in rotation 3 yields 56.1 bushels and shows a positive trend of 0.46 bushel as against a yield of only 42.3 bushels and a definite negative trend of −0.52 bushel in rotation 4, in which no manure is used. The average yields of the continuous wheat plats in rotation 11 with the application of manure show a slight positive trend while those in the corresponding rotation 12, continuous wheat without the application of manure, show a definite negative trend. The manure in all the rotation plats, designated as plus manure in Table 1, is applied at the rate of 15 tons per acre every third year.

A correlation between the average yields of the 14 wheat plats included in the various rotations and their respective trend evalua-

tions showed a value of "r" $=0.8025\pm.0666$. A corresponding calculation of "r" for the average yields and trend evaluations in the case of the eight oats plats gave a correlation of $0.8779\pm.0584$.

STRAIGHT LINE YIELD TRENDS IN RELATION TO RAINFALL TRENDS

The yield trends exhibited by crops in a series of rotation experiments may be due either to induced soil changes or to variations in climatic conditions, especially moisture relationships, over the period of the test. The influence of moisture relationships will be especially disturbing in the event of progressive changes in a given direction. That such progressive changes did not play a significant part in the trends of yields shown by the crops in the rotation systems under discussion is brought out in Table 2 giving the annual and seasonal trends in precipitation at Moscow, Idaho, for the duration of the rotation experiments. The most significant positive trend is exhibited for the winter months of December to March, inclusive. The annual precipitation shows but a slight positive trend, while the August to November, as well as the April to July, trends are slightly negative.

TABLE 2.—*Annual and seasonal trends in precipitation at Moscow, Idaho, for the period 1915 to 1937, inclusive, calculated by the method of least squares.*

Periods of precipitation	Rainfall trends	Equation of line of least squares	Extremities of trend lines
Annual	+0.09	$y= .09x+20.23$	20.23–22.21
Aug., Sept., Oct., and Nov.	−0.02	$y=-.02x+6.14$	6.14–5.72
Dec., Jan., Feb., and March	+0.14	$y= .14x+8.94$	8.94–12.02
Apr., May, June, and July	−0.04	$y=-.04x+5.20$	5.20–4.32

PARABOLA TRENDS OF YIELD DATA

The graphic presentation of the seasonal yields suggests the possibility that a curved line may fit the obtained yield data better than a straight line. That this is the case in most instances is brought out in Table 3 giving summations of the total deviations, plus and minus, of the actual and the calculated values of y. Figs. 1 and 2 give the straight line and the parabola trends of the seasonal yields of the wheat in rotation 1 and the oats in rotation 4. A second order parabola is used for these calculations, the equation for which is $y=ax^2+bx+c$. This equation demands the solving of three unknowns, a, b, and c. When these values are determined, y may be calculated for any selected value of x.

It will be observed from Table 3 that the closeness of fit of the yield data to the trend lines is not materially better for the parabola than for the straight line trends. As a matter of fact, in the case of the oats in rotation 1, the linear trend gives a slightly better fit than the curvilinear one.

The fact that the parabola trends fit the data as well or slightly better than straight line trends brings out one fact, namely, that the upward trends, and in some instances the negative ones, were not at the same rate for the entire period covered by the experiment. In the

case of those rotations showing positive trends the upward swing of the yields was greater during the initial than for subsequent periods. This same fact can also be demonstrated by calculating the straight line trends for the first 11 and the subsequent 12 years over which the experiment extended. In other words, the yields on some of these rotations are approaching an equilibrium.

TABLE 3.—*Comparative total deviations of actual seasonal yields from calculated straight line and parabola trends of the crops in specified rotations.*

Rotation No.	Crop	Av. yield in bushels per acre	Straight line trend	Summation of deviations of actual and calculated values of y	
				Straight line trend	Parabola trend
1	Wheat	52.9	+1.26	332.0	296.1
1	Oats	63.5	+1.26	361.0	365.4
3	Wheat	56.4	+0.96	287.9	268.2
3	Oats	56.1	+0.46	419.5	399.7
4	Wheat	52.5	+0.63	227.9	205.6
4	Oats	42.3	−0.52	240.5	236.2

While it is valuable to demonstrate that the yield data shows unequal trends for the period covered, the parabola trend is difficult to visualize and, as has previously been discussed, is for that reason less usefull for the presentation of trend relationships to the layman than straight line trends. The slope of the straight line is determined by only one unknown, a, while the course of a second order parabola is determined by two unknowns, a and b. The unknown c in the equation determines the point of origin or the y intercept of the curve. Somewhat better fits than obtained could be secured by the use of a third order parabola. It is doubtful, however, if the slight improvement in the closeness of fit would justify the extra calculations involved.

The parabola trend has one decided fault in its application to the rotation yield data here presented in that it produces a curve tending downward at increasing rates towards the end of the cycle. The actual yields give no evidence of the occurrence of such dips but rather show that they may be maintained at around their present levels. At any rate, either increases or decreases, as the case may be, will be gradual rather than at accelerating rates.

VARIABILITY OF SEASONAL YIELDS

The comparative variability of the seasonal yields of separate crops or of plats receiving different treatments serves as an index of the reliability of such yields. Klages[3] made use of the seasonal variability of yields in relation to crop adaptation studies. The axiom was established that the ecological optimum of a given crop was approached

[3]KLAGES, K. H. W. Geographical distribution of variability in the yields of field crops in the states of the Mississippi Valley. Ecol., 11: 293–306. 1930.

———. Geographical distribution of variability in the yields of cereal crops in South Dakota. Ecol., 12: 334–345. 1931.

in those particular locations where the yields of the crop in question were found to be uniformly high and showed a low degree of variability.

The variabilities in the seasonal yields of the various crops included in the rotation systems at Moscow from 1915 to 1937, as evaluated by the coefficient of variability, are given in Table 1. When considered in the light of their respective probable errors and on the basis of significance, most of the values are remarkably alike, yet some interesting differences are in evidence. The wheat yield in rotation 4 shows a significantly lower degree of variability than that of the oats. The same is true also in a comparison of these two crops in rotations 6 and 8. The potato crop in rotation 8 gives the highest variability of any of the crops grown. The relatively low yields and high degree of variability of this crop would indicate that potatoes are not especially well adopted to conditions prevailing in the Palouse area.

SUMMARY

Variability studies of seasonal yields may be expected to be of value to supplement yield data in cases where a sufficiently long enough period is covered by the experiment for definite statistical analysis. They are especially desirable in the analysis of the yield data of experiments extending over a period of 25 years or more.

Trend relationships of the yield data of 10 crop rotation systems conducted on the University Farm at Moscow, Idaho, are presented to show that yield data of long time experiments and especially of crop rotation data may be supplemented to advantage by trend studies.

While straight line trends are not applicable to all compilations of yield data, they provide in cases where they fit the data a good index of the general or average slope of the trend line of yield tests extending over a period of years which can be used to advantage in the analysis and presentation of the results. In cases where the date exhibits variable trends for different periods of the experiment, it is necessary to resort to curvilinear trends in order to formulate the trend relationships. In the crop rotation yield data analyzed, the closeness of fit of the yield data to the trend lines was not materially better for parabola than for straight line trends.

NOTE

THE CHALLENGE OF AGROBIOLOGY

THE review of my "A B C of Agrobiology" by "R. B." in the March (1938) number of this JOURNAL raises an issue on which a little comment may be in the general interest. On page 265 the reviewer says:

"In addition to being the A B C of Agrobiology one gets the impression that this book is also the X Y Z of the subject. Its problems are solved! The job is done. Its laws are all discovered. They are immutable and universal; . . . ."

In the first place, the reviewer is assured that this is very nearly, if not quite, the impression that the book was intended to convey.

In the second place, the half-derisive tone of the review seems to indicate that the reviewer himself entertains no conviction that the problems of agrobiology have been solved, that its job has been done, that its laws have been discovered, or that, if there are any laws of agrobiology, these laws have any claim to universality or immutability.

If this aloofness were only the reaction of a single individual it would scarcely call for notice, but the author has had ample occasion to note that it reflects the state of mind of many plant biologists and agronomists. The vastness of the plant world, the diversities of characters of plant species, and the number and variability of the environmental influences that affect the growth and yield of plants have induced an age-old feeling that here is a great tangle which it were presumptuous to expect any man or set of men to untangle. Most incredible of all appears to be the assertion that the quantitative phenomena of plant life are reducible to a single universal rule that partakes of the nature of an immutable law of Nature.

In committing themselves to the principle of universality and immutability agrobiologists are well aware that they are suspending their basket of eggs by a single thread which any passer-by may essay to cut. For, let there be found a single authentic exception to the rule of universality, and the whole agrobiologic proposition is done away. The universality here contemplated is contained in the theorem that the nutrition and growth of all plant types, without known exception, are controlled and directed in a determinate manner by the mass action law.

The purpose of this note is to indicate a simple experiment by which anyone may try his hand at blowing up this proposition and with it the whole tribe of agrobiologists. Let there be prepared a series of equal portions of a normal soil. Let there be grown in each of these portions of soil the same stand of *any* pure bred plant genotype or stabilized agrotype under the varied influence of graded amounts of *any* recognized factor of plant growth. (Note that the reference to *any* plant type and *any* growth factor gives full scope to the principle of universality.) If the resulting series of yield figures do not fit accurately in the agrobiologic yield equation $\log(100-y) = 2-0.301x$, then the agrobiologic basket is hopelessly smashed. If the fit is accurate, then the whole case for agrobiology is fully proved because any

plant and any growth factor, i. e., all plants and all growth factors, will have given the answer.

The whole argument is thus reduced to a question of the validity or invalidity of a single working equation, and this is a question that can be resolved experimentally. If the equation does not hold for any case, there is nothing more to be said. If it holds in every case, the vital principles of agrobiology, including the law of the constancy of the effect factors of growth factors, the inverse yield-nitrogen law, the concept of plant life as a definitely limited quantity, and the whole system of the new agrobiologic dynamics by which the quantitative reaction of plants to the positive factors of their growth can be calculated in advance, *et cetera*, become fully established because the validity of each and all of these agrobiologic fundamentals is guaranteed by the validity of the parent mass action equation.

It will perhaps be natural to ask, How did the agrobiologists acquire confidence (or cock-sureness, if you will) in their conclusion that the main problems of agrobiology have been solved? This confidence is founded on a record of experimentation and research in many countries, both temperate and tropical, by many investigators who have worked with practically all plant species of economic importance. The suggestion that plant nutrition and growth are the result of a mass action of the classic type was put forward 30 years ago by Mitscherlich, who to date has made nearly 8,000 controlled experiments that have consistently verified the suggestion. Mitscherlich's lead has been followed by contemporary workers both academic and practical who have clarified and expanded Mitscherlich's original concept and have multiplied the number of his experiments manyfold.

It is not denied that some investigators, including at least one American biochemist of Welsh extraction, have offered experimental refutation of the Mitscherlich theorem. Agrobiologists have a certain standard of experimental accuracy and precision that they impose on their work. These standards include recognition of the fact that plant growth depends on all its positive factors (not one can be missing); that hostile negative factors must be excluded from the environment; that the law of conflicting attributes of growth factors must be respected; that experimental conditons must be uniform and constant; and that the test plants or seeds must be uniformly viable. Agrobiologists cannot quarrel with the results of such an experiment, but they need not be expected to accord respect to work (past, current, or future) that does not measure up to this standard.

In view of what an established agrobiology has to offer, no agronomist charged with the public duty of promoting effective farming practices, and no conscientious teacher of the principles of plant nutrition, will be justified in neglect in orienting himself for or against the tenets of agrobiology, preferably by intelligent experiment or at least by an open minded examination of the record.—O. W. WILLCOX, *Ridgewood, N. J.*

BOOK REVIEW

AGRICULTURAL ANALYSIS: A HANDBOOK OF METHODS EXCLUDING THOSE FOR SOILS

By C. Harold Wright. London: Thos. Murby & Co. VII+343 pages, illus. 1938. 16/.

THE title of this book indicates clearly its purpose and content. Designed as a laboratory manual for agricultural analysts with limited library facilities, the book gives methods of analysis of fertilizers, feeding stuffs, milk, milk products, insecticides, and fungicides, together with references to sources of information. It also describes the preparation of the indicators and standard solutions called for in the various procedures and data necessary for calculating results.

Both official methods and alternative methods are given, except where one method is deemed much superior to others. Special attention is given to recent developments, such as determinations for the mineral constituents of feeding stuffs and to the analysis of derris and pyrethrum.

Tables of the International atomic weights and of gravimetric and volumetric factors and their logarithms and an index of authors and subjects add materially to the value of the book. (J.D.L.)

AGRONOMIC AFFAIRS

MEETING OF AMERICAN SOYBEAN ASSOCIATION

THE annual meeting of the American Soybean Association will be held at Wooster and Columbus, Ohio, September 12, 13, and 14, for the primary purpose of summarizing important facts regarding the growing and utilization of soybeans.

The meeting will convene at noon on September 12 at the Experiment Station at Wooster and will include an inspection of the soybean investigations of the Agronomy Department and of animal feeding experiments which involve the use of soybeans.

On September 13 and 14 the group will meet at Columbus for an inspection of field plat experiments with varieties and cultural practices for soybeans and of exhibits of machinery for soybean growers, industrial products made from soybeans, and soybean products for human food. A program of papers dealing with recent developments in the growing and utilization of soybeans will also be arranged.

For further details on this meeting, write to Professor J. B. Park, Department of Agronomy, Ohio State University, Columbus, Ohio.

MEETING OF WESTERN BRANCH OF SOCIETY

THE Western Branch of the American Society of Agronomy will meet at the University of Arizona, Tucson, Arizona, August 31 to September 2. For further details concerning the meeting, write Ian A. Briggs, Secretary, Western Branch of the American Society of Agronomy, University of Arizona, Tuscon, Arizona.

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MEASURING CROP YIELDS ON A COMMUNITY SCALE[1]

FRED S. REYNOLDS AND ALBERT E. COLDWELL[2]

WHEN the Soil Conservation Service demonstration project Tex-3, near Dalhart, Texas, had been in operation for about three years it was apparent to the project staff members that satisfactory results were being obtained by methods of water conservation, the chief of which were contour farming and terracing. However, it was felt that these observations alone were not sufficient to convince many persons except those who had the opportunity to visit the project and inspect the results. So a method of measuring the yield of grain sorghums on all the fields in or near the project area was devised, and the information gained was significant enough to justify an explanation of the method and an analysis of its accuracy.

This paper is not intended to enter the field of research, as the yield measurements were made for only one year. It is planned to repeat them each year but conditions will not be controlled from year to year. Hence it is felt that the value of the measurements lies in the large acreage which they represent.

The object was to perfect a dependable, quick, and practicable method of measuring crop yields of fields ranging up to 640 acres or sometimes larger. The plan must be applicable to any size field of any shape, regardless of the number of acres. In other words, the rate of yield is the information sought. The total yield of a field is then found by multiplying the number of acres by the rate of yield per acre. Although the accompanying results are for sorghums only, the same method, with slight modifications, could be used for small grains.

The yield measurements in 1937 were made primarily to evaluate the terracing and contouring practices being advocated by the Soil Conservation Service. Secondary in consideration were comparison of soil types in yielding capacity and effectiveness of various crop residues in controlling wind erosion. As the work progressed refinements were added, and it is believed that the same measurements

[1]Contribution from the Soil Conservation Service, Dalhart, Texas. Received for publication April 5, 1938.

[2]Associate Agronomist and Junior Engineer, respectively.

can be made more accurately next year by including all these improvements from the beginning of the season.

The Soil Conservation practices being followed by the cooperators and many other farmers need to have an economic value placed on them. In order to do this the grain sorghum yields on the farms of the Dalhart area were measured. So far as known, there was no method commonly used on a large field scale to do this. Measurements were made on 63 fields in the area consisting of 11,485 acres with a variation of soil types and farming practices being followed. These were grain sorghums and had to be measured after the grain was matured and before harvest. This period is normally from October 1 to November 15; therefore, any method used had to be quickly applied.

There is need to know the productive capacities of the various soil types. The terraces and other mechanical structures need to be evaluated also. It is believed, therefore, that the Conservation Service was fully justified in going to the nominal expense of measuring these yields, which in turn serve as a basis for studying effectiveness of the practices.

With this method it is believed that the present staffs on the Soil Conservation Service projects can, if the need arises, measure the yields on all the fields under agreement and many others in addition.

County agents may use this method quite effectively in promoting terracing, contouring, and other desirable farm practices in their counties, by organizing 4-H clubs to measure the yields on all terraced and contoured fields and as many or more untreated fields to be used for comparison. This brings out the real merits of a type of treatment in such a way that farmers can readily grasp them.

PLAN OF WORK

To begin with, the idea of sampling a field many times was uppermost in mind. In order to carry out this idea, three fields, one terraced and two straight-rowed fields, all representative of the area, were selected to try out various modifications of the sampling theory on each field.

The equipment used consisted of a record sheet for recording the field work (Fig. 1), pencil, a 5-foot measuring rod with inch graduations, a pocket knife, and a shoulder sack for collecting samples.

Rules for sampling on a field were as follows: (a) Roughly divide the field into three or more equal lengths or segments. (b) Go straight across the field in the center of each of the equal segments and at approximately right angles to the direction of the rows. (c) Stop at the 24th row and measure off 10 feet of the 24th and 25th rows. (If the rows are not perpendicular to the path followed use a paced distance equivalent to 24½ rows.) Do this in such a way as to eliminate the human element. For instance, always measure to the same side. (d) Collect the first five heads of the 10-foot segment of the two rows and put in the sack to be taken in for weighing. (e) Count all the heads in the two-row 10-foot segment and record. Also record number of heads taken, for many times there will be less than five heads. (f) Then

CROP YIELD SURVEY

Name____________ Date__________ Field______ Sheet No._____

How Farmed__________ Direction__________ Part of Field________

Made Count on________ No. Rows______ Feet______ Acres in Field_____

Surveyor__________ Total Heads__________ Total Heads Taken________

Green Wt.______ Dry Wt.______ Length of Sample Area__________

No. count		No. Heads	Heads Taken	No. Stalks	Height Inches	Terrace No.	Distance from Nearest Terrace Above or Below		Crop and Variety
1	22								
2	23								
3	24								
4	25								
5	26								
6	27								
7	28								
8	29								
9	30								
10	31								
11	32								
12	33								
13	34								
14	35								
15	36								
16	37								
17	38								
18	39								
19	40								
20	41								
21	42								

Mark through numbers not used

FIG. 1.—Typical record sheet for field work.

proceed again across the field with the count of 1 until the 24th and 25th rows are reached, and so on across the entire field.

DISCUSSION OF RESULTS

The above method was modified on the three fields with the results given. At first four apparently average heads were taken, but this was thought to be inaccurate by allowing the human element to enter in. Table 1 gives results of from two to five yield measurement tests on each of the three fields.

TABLE 1.—*Results of yield measurement tests on three fields.*

Field	Yield of headed grain, lbs. per acre					
	No. heads taken for weight					
	2 rows 10 ft. long			2 rows 20 ft. long		
	4	5	All for 10 ft.	5	10	All for 10 ft.
Bill Roper, 46 acres	——	2,067	2,095	2,111	——	2,140
C. J. Roberts, 160 acres	1,190	——	1,152	——	——	——
J. M. Hester, 80 acres:						
Oct. 12	456	——	490	——	——	——
Nov. 3	——	——	——	393	412	——
Omitting block method	——	——	——	——	——	——

Field	Yield of headed grain, lbs. per acre		
	Block method	Average of all trials	Percentage of variations from average yields
Bill Roper, 46 acres	——	2,103	±1.06
C. J. Roberts, 160 acres	——	1,171	±1.62
J. M. Hester, 80 acres:			
Oct. 12	518	——	——
Nov. 3	——	454	±9.03
Omitting block method	——	438	±8.44

By referring to Table 1 it is seen that Roberts' and Hester's fields were measured to compare yields from four average heads with that from all the heads for the 10-foot samples. Roberts' yield was 1,190 for the four-head sample and 1,152 for the 10-foot samples. However, Hester's was smaller for the four-head samples as compared with the 10-foot sample, being 454 and 490, respectively. Since trying to select four average heads was slow and introduced the human element, it was abandoned. Therefore it was decided to try taking the first five heads that the operator came to in each sample area. This is equivalent to picking the heads at random. Another reason for taking five heads was to increase the number of heads taken for weighing and to expedite the work of taking the samples. The operator can rapidly cut

the first five heads and put them in his sack without hesitating to estimate mentally if they are of average size.

Roper's field was also used to compare results with several modifications of the sample method. The operator took five heads, then all the heads for 10 feet, for weighing, then counted the heads on an additional 10 feet or a total of 20 feet in a sample area. Then the calculations were made on the following basis:

A. 5 heads on 10-ft. basis.
B. 5 heads on 20-ft. basis.
C. All heads for 10 ft. on 10-ft. basis.
D. All heads for 10 ft. on 20-ft. basis.

The results ranged from 2,067 to 2,140 pounds per acre, or an average of 2,103.25 pounds.

The field had 46 acres and was sampled 27 times, or once to every 1.7 acres. It is believed that 2,140 pounds is nearer the actual yield than any other figure because this is based on a 20-foot length of sample with all the heads for 10 feet of this length being harvested for weighing. It is obvious that the more samples taken and the larger the individual samples, the more accurate the results. Roper's field was one of the heaviest yielding of those measured; likewise one of the most uniform throughout.

Continuing the discussion of the five-head sample, it is to be seen in Hester's 20-foot length sample that five heads gave 393 pounds as compared with 412 pounds for the 10-head sample. Observe that this is the same field mentioned previously where the yield was 454 pounds and 489 pounds, respectively, which was taken several weeks earlier.

Hester's field varied from 393 pounds to 518 pounds in the five trials made for the purpose of developing a yield measurement plan. This difference of 125 pounds, or about 25%, is entirely too great to pass up without further comment. The block method giving 518 pounds was the highest. Briefly, this method is so designated from selecting four blocks of 2,500 square feet each, one near each of the four corners of the field, and harvesting all the heads in each block for weighing and calculating to an acre basis. This was slow and cumbersome and necessitated the harvesting of too great a yield and permitted the human element to creep in. However, the human element could easily be removed by previously plotting the field and predetermining the location of each block. Too few samples are secured by this method, so results would not be representative in most of the fields with only four blocks or samples taken, therefore this method was discarded. Studies were continued, however, on the basis of the smaller samples in large numbers widely and uniformly distributed over the entire field, with the belief that this procedure gave more promise than any other.

The remaining four yields of the Hester field of 454, 489, 393, and 412 pounds, respectively, are analyzed further in Table 2 to determine why heavier yields were obtained in October than in November.

A study of the figures in Table 2 may be made by comparing the October yield of 490 pounds with the 412 pounds of November, for

TABLE 2.—*Analysis of repeat sampling on Hester field to determine factors responsible for variation in calculated yields.*

Factors considered	Harvested Oct. 12		Harvested Nov. 3	
Calculated yield, lbs. per acre	456	490	393	412
No. heads per sample area, reduced to 20 ft.	13.84	13.84	11.67	13.78
Average weight of heads, lbs.	0.1040	0.1116*	0.1062	0.0944*
Weight of heads per sample area, lbs.	1.44	1.54	1.24	1.30
No. of areas sampled	38	38	18	18
No. of heads weighed	101	263	80	143
Total No. of heads in areas sampled	263	263	210	248

*Difference in these two figures is factor responsible for difference in yield, but no explanation can be given for it.

the reason that these two yields are based on the larger number of heads for each of the dates.

The field was quite spotted, in which case repeat tests could be expected to vary. Furthermore, the October trials included 38 sample areas, while the November one had only 18.

The fact that the November tests were made 22 days after the October tests might be thought to have permitted the heads to dry out, but all samples were dried to a constant weight for calculations so this should not have been a factor here.

In order to speed up the yield measurements during the last part of the field work a change was made by taking samples on the 49th and 50th rows, measuring 20 feet for the sample area and taking only five heads for weighing as before.

A study was made to determine whether it was necessary to make observations as close as every 24 and 25 rows or whether they might be widened to 49 and 50 rows, thus reducing the field work perhaps a third. By taking samples on the 49th and 50th rows and crossing the field at quarter mile intervals, one man can measure the yields on 300 to 500 acres of grain sorghums a day. For this study eight fields, four of which were spotted and four quite uniform in yields, were selected for further analysis as reported in Table 3.

Only one survey was actually made of each field on the 24th and 25th rows. The figures for the 49th and 50th rows were arrived at by using the even numbers 2, 4, 6, etc., omitting the odd numbers of the survey.

It will be seen that the spotted fields varied from +10.7 to —23.9%. The uniform fields had less variation, ranging from +6.7 to —6.2%. This indicates that it is necessary to take more observations on the spotted fields, while the uniform fields need not be sampled as many times to arrive at the approximate yields.

It may safely be said that the accuracy of these yield measurements varies directly with the uniformity of the grain throughout the field. That is, the results from the more uniform fields are more accurate than those from the less uniform ("spotted") fields.

Tests made on a theoretical field with exceedingly "spotted" yields scattered throughout the field at random indicate that this method of sampling is correct to within ±20%, and because of the

TABLE 3.—*Comparing yields obtained by sampling the 49th and 50th rows with that taken on the yields obtained on the 24th and 25th rows, all calculations based on the yields obtained on the 24th and 25th rows.*

Fields	Pounds per acre		Variation of 49th and 50th rows from 24th and 25th rows	
	Rows 24 25	Rows 49 50	Pounds per acre	Percentage based on 24th and 25th rows
Spotted Fields				
Taylor, 461	250.5	190.6	−59.9	−23.9
Mitchell and Robison	399	425	+26	+6.5
C. A. Petty	765	847	+82	+10.7
C. J. Roberts, north of house	889	848	−41	−4.6
Uniform Fields				
Bill Roper	2,067	1,939	−128	−6.2
W. H. Green	1,568	1,481	−87	−5.5
Peden N. W. ¼	1,149	1,226	+77	+6.7
Knight Sec. 16	918	958	+40	+4.4

fact that none of the fields are as spotted as the theoretical one, the yields on which ranged from 0 to 1,500 lbs. per acre, it is believed that the actual results are in the main accurate to within ±10% and ±5% in most cases.

Actual field measurements to determine comparative accuracy bear out this contention. On a field with high yield, which necessarily indicates uniformity, repeat samples varied less than ±2% from the average results, whereas on a "spotted" field the repeat samples varied as much as ±9% from the average. (See Table 1.)

The question, "How near are the calculated yields to the actual harvested yields?", has been repeatedly asked. There are so few fields where the entire yields were segregated and measured that this question can not be definitely answered in most cases.

Where estimates by farmers based on some form of measurements were made, they agree pretty well with calculated yields. There were one or two, however, who questioned the calculated figures, claiming their harvested yields did not agree with the survey figures.

It was found that estimates or guesses varied widely from calculated yields, ranging from below to far above, as might be expected. In the majority of the cases estimates are in round numbers such as 1,000, 1,500, or 2,000 pounds per acre.

It is interesting to note how one farmer, "D", over-estimated one field by estimating 2,500 pounds for a field calculated to be 1,650 pounds, and made a greater error in the opposite direction by estimating 635 pounds for a field calculated to be 1,568 pounds. Both fields were later combined with the actual production in line with calculated yields. Another field was surveyed at 46,270 pounds while yet

in the field. The owner later reported that he headed it and sold the entire amount, 23 tons, or 46,000 pounds.

At the time of making the survey a few were asked to estimate their yields so that their figures could be compared with the results of the survey. Table 4 gives the results of the information thus obtained.

TABLE 4.—*Comparing owner's estimate with calculated yield on five fields.*

Farmer	Acres	Owner's estimate		Calculated		Variance of estimate of total amount from calculated	
		Acre yield, lbs. per acre	Total amount, lbs.	Acre yield, lbs. per acre	Total amount, lbs.	Minus	Plus
A, Heiskell..	70	1,220	85,400	1,457	101,990	—	16,590
B, Blades...	240	700	168,000	744	178,560	—	10,560
C, Peden...	500	1,500	750,000	964	482,000	268,000	—
D, Green...	55	2,500	137,500	1,650	90,750	46,750	—
Green......	27	635	17,145	1,568	42,336	—	25,191
E, Ritchey..	—	—	46,000 sold	661	46,270	—	270
Totals....	892	—	1,158,045	—	895,636	314,750	52,611

It will be observed that some over-estimate while others under-estimate the yields. The estimates however, are far too unreliable to be used as a yard stick in measuring the value of soil conservation practices. The average number of acres represented by one sample was 3.7. However, this figure varied from 1 acre to 11 acres while measuring yields on a little more than 11,000 acres.

This method of measuring yields is well adapted to grain sorghums, but modifications would probably have to be applied in order to measure small grain or grass yields. The sample areas would have to be smaller, and probably the whole crop in each sample area should be harvested. However, no matter what crop is to be measured, it is felt that the suggestions outlined for dividing the field into parts and calculating yields to an acre basis will be of value.

SUMMARY

1. A method of measuring crops and grass yields while still in the field is needed.

2. The farm practices, such as furrowing, ridging, contouring, and terracing, on ranch and farm lands need to be evaluated.

3. A method of calculating yields was perfected. The method is based on securing a large number of small samples uniformly distributed so that all parts of the field are proportionally represented.

4. The samples are weighed and yields calculated to an acre basis.

5. On fields from 80 to 640 acres, one sample should represent not more than from 3 to 5 acres.

6. Each field to be surveyed should be observed for kind of crop, shape and approximate size, and a route of march to obtain samples decided upon.

7. The actual samples should be chosen in such a way that the human element is reduced to the minimum.

8. The more uniform the crop, the more accurate the calculated yield will be. Therefore, fewer samples are required from the heavy yielding fields, which are also uniform, than from spotted and light yielding fields.

9. Calculated yields may safely be said to be within $\pm$ 10% of the actual yield.

10. Farmers' estimates are not sufficiently accurate to be used as a yard stick in measuring the value of soil conservation practices.

11. One man can measure the yield on 300 to 500 acres of grain sorghums a day.

A PROMISING WILT-RESISTANT LONG STAPLE COTTON[1]

D. C. NEAL AND C. B. HADDON[2]

A SELECTION of Delfos cotton made at the Northeast Louisiana Experiment Station, St. Joseph, Louisiana, by the junior author, in 1934, has exhibited marked resistance to fusarium wilt in tests conducted for the past three years on the heavily infested wilt plots at Baton Rouge, Louisiana.

In a test of 16 varieties of cotton in 1936 at Baton Rouge for wilt resistance it was noted that this selection of Delfos was one of the outstanding wilt-resistant varieties, with productivity also fairly good. In a further test of 10 new strain and hybrid cottons for wilt resistance in 1937, the Delfos selection, namely, Delfos 2323-965-425, remained almost free of wilt throughout the season, showing, as late as September 8, only 0.5% infection of a total population of over 600 plants. In comparison, Half and Half, a susceptible variety with a population of 516 plants, developed approximately 63% wilt. In one series, comprising row sections 100 feet long in which the above varieties were compared, Half and Half developed 100% infection by September 8, while the Delfos remained entirely healthy (Fig. 1).

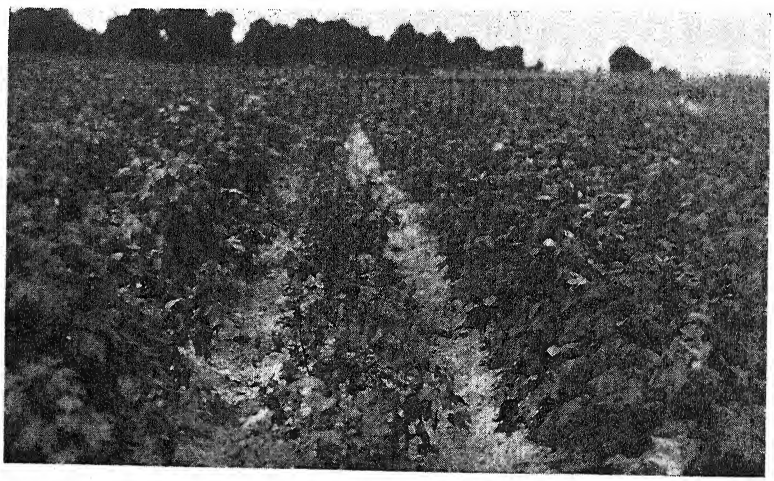

FIG. 1.—Wilt infection in new strain and hybrid cottons at Baton Rouge, La., in 1937. Left, Stoneville X D. P. L. 4-8; center, Half and Half; right, Delfos 2323-965-425. Photographed August 4.

This wilt-resistant selection was originally made from a plant of Delfos 2323-965 cotton which remained healthy throughout the season of 1934 in an infested area on the experiment station plots at

[1]Joint contribution from the Bureau of Plant Industry, U. S. Dept. of Agriculture and the Louisiana Agricultural Experiment Station. Received for publication April 9, 1938.

[2]Senior Pathologist, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Superintendent, Northeast Louisiana Experiment Station, respectively.

St. Joseph, Louisiana. The selection grew vigorously producing a normal crop and fruiting about as early as any of the Delfos plants not in the infested area. The staple length was 1 5/32 inches full. In 1936, the seed from the selection was again planted in the wilt area and again it remained healthy throughout the season, producing a splendid yield of 1 3/16-inch cotton.

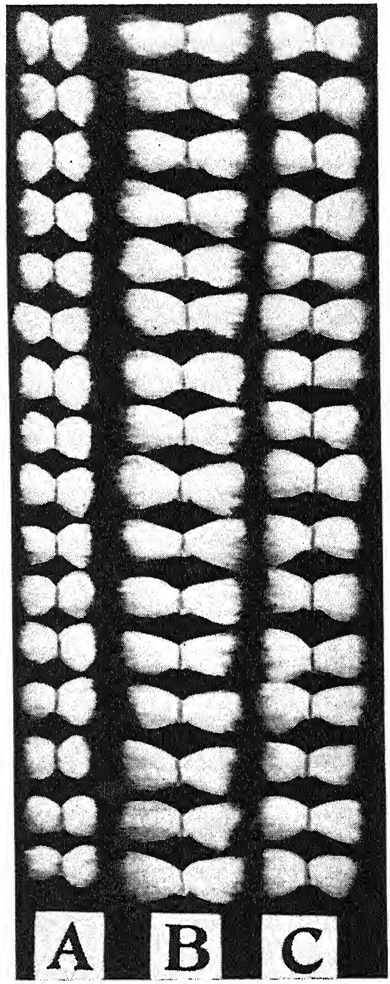

FIG. 2.—Comparison of staple length and fiber uniformity of one susceptible and two wilt-resistant varieties of cotton grown at Baton Rouge, La., in 1937. A, Half and Half; B, Delfos 2323-965-425; C, Dixie-Triumph P -32.

YIELD, STAPLE LENGTH, AND FIBER UNIFORMITY

On the "bench" or "bluff" soils at Baton Rouge this cotton has produced over 1,100 pounds of seed cotton per acre, following moderate applications of an N.P.K. fertilizer. At the Northeast Louisiana Delta Experiment Station, where it was included in a variety test for the first time in 1937, the yield has been in excess of a bale per acre (Table 1). The staple averages 1⅛ inch on bluff soil and from 1 5/32 to 1 3/16 inch in the Delta. The lint averages about 32.5%. Combings of seed locks collected from 16 bolls near the middle portion of individual consecutive plants in a row show that the fiber possesses good uniformity (Fig. 2).

PLANT TYPE

The selection is fairly representative of the Delfos 6102 type in growth habit, rapidity of fruiting, leaf characters, boll size, and fiber properties. It is unlikely that it is a natural hybrid.

AVAILABLE SEED SUPPLY

At the present time, as would be expected, very little seed of this strain is available. However, plans are now being made to increase it as rapidly as possible for ultimate release to growers chiefly in the wilt-infested districts of the Delta. Sufficient stock should be available in 1939 for planting approximately 150 acres of this selection.

TABLE 1.—*Comparison of yields of Delfos 2323-965-425, a wilt-resistant selection, and six standard varieties at St. Joseph, La., in 1937.*

Variety	Seed cotton per acre, lbs.
Delfos 2323-965-425, Wilt Resistant	2,246
Washington (Delfos 719)	2,130
Ambassador (Stoneville 4A)	2,321
Delfos 9252	2,110
Ark. Acala 1114	1,902
Rowden 2088	2,096
Delfos 130	2,588

GENERALIZED STANDARD ERRORS FOR EVALUATING BUNT EXPERIMENTS WITH WHEAT[1]

S. C. Salmon[2]

GENERALIZED probable or standard errors have often been used for evaluating the results of field experiments for the reason that they are believed to be a better measure of random variation than can be derived from the small number of plats of each variable characteristic of such experiments. Those who first used this device seem to have clearly realized that it provided approximate values only and that certain assumptions were involved which might or might not hold true.

Curiously enough, in the light of later developments, it formerly was quite generally assumed that the random error was highly correlated with yield or whatever was being measured. Thus, the characteristic feature of the "deviation of the mean" method devised by Hayes (4)[3] consisted of expressing the standard error or probable error as a percentage of the mean yield, which was then applied to the yield of each individual variable. The validity of this procedure obviously depended upon the above assumption. Hayes and Immer (5) presented evidence for such a relation in varieties of wheat, but later in a more extensive study involving several crops, Immer (7) found none.

With the advent of analysis of variance, all thoughts of a possible relation between standard error and yield and other metrical attributes seem to have vanished. At least those who advocate this method seldom or never mention or emphasize the assumptions on which validity depends, nor is the degree to which they actually are realized in particular cases seriously considered. Furthermore, it appears to be assumed that by this method an accurate estimate of random error for any and all properly conducted experiments is assured.

Altogether the current situation with respect to the use of generalized estimates of random error can be characterized as nothing less than anomalous, as may be seen from a consideration of the manner in which analysis of variance has been used and the problems to which it has been applied. Thus, several workers in recent months have used it to interpret various disease-resistance trials with small grains in which a single error term is derived and applied to all varieties indiscriminately regardless of the range of infection between varieties. This range in some cases has varied from 0 or near 0 to 75 or 80%.

If it is not clear that the standard errors for varieties immune from or highly resistant to disease are materially different from those for varieties in which, say, 50% of the plants are infected, a casual consideration of the binomial formula for standard error will show that such is quite certain to be the case. The binomial, it may be noted, is

[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication April 16, 1938.

[2]Principal Agronomist.

[3]Numbers in parentheses refer to "Literature Cited", p. 662.

usually considered especially applicable to discrete data such as those being considered in which the plants fall into two categories, those that are diseased and those not diseased. As shown by this formula the relation between standard error and infection is curvilinear, the standard error being a maximum with 50% infection and 0 with 0 and 100% infection. The situation is further complicated by the fact, as will be shown later, that in some cases—perhaps in many—neither the binomial nor generalized errors derived by analysis of variance as applied in the usual way can be considered as valid estimates of random error.

Also, certain workers recently have applied a single error term derived by analysis of variance to field crop data from several locations and extending over a period of years without any attempt to show that the errors are in fact the same for all locations and years. Anyone familiar with field plat experiments knows they often are not. Apparently, analysis of variance has often been used in such cases without realization on the part of the user that any assumptions as to similarity of variance or standard errors were involved.

The primary purpose of the present paper is to indicate the relation between standard error and infection in certain experiments dealing with resistance of varieties of wheat to bunt, to illustrate some of the difficulties attending a statistical analysis of such data, and to point out some of the serious errors almost certain to result from a blind, indiscriminate use of current statistical methods for such data. An attempt also will be made to analyze the data statistically by what is believed to be a sound, reliable procedure, but, as will appear later, a critical consideration of the proper methods to apply is in the main left for the attention of others.

MATERIALS AND METHODS

The data used in the present paper were obtained by Rodenhiser and Holton (8) as a part of their studies with physiologic races of bunt. The general description of the tests and the technic employed has been given by them. Briefly, the latter consisted of growing duplicated short rows (5 to 8 feet) of each host tester, the seed having been inoculated with spores of the desired collection of bunt. A single row of each variety inoculated with each collection of bunt was seeded and the entire seeding was then repeated in the same order. In other words, the duplicated rows were systematically distributed throughout the experimental area. Infection was recorded as a percentage of the total number of heads counted at or near harvest time. The number counted was seldom less than 200 and was sometimes more than 400 per row.

A dozen or more tests of the kind considered herein have been conducted during the past five or six years, but because of unfavorable soil or weather conditions at or soon after seeding, a satisfactory degree of infection and uniform infection has not always developed. For the purpose of this study, five experiments were selected on the basis of high infection in the susceptible varieties and reasonably uniform infection throughout the experiment. Both winter and spring wheat have been included. The varieties used as host testers, the location of the tests, and other details regarding them are given later in tables in connection with the experimental data.

The first objective of the study was to determine the magnitude of the error introduced by calculating a generalized standard error for all varieties. It appeared that this could be done by calculating separate standard errors first for each variety and second for each collection of bunt. It soon appeared that the objective could be attained from a comparison of the varieties of wheat alone, and the calculations for collections of bunt were discontinued and none of the results pertaining thereto is presented. The standard errors were calculated by analysis of variance and thus measure the fluctuation of the members of each pair of rows about the mean of each pair. If this method is not accurate when applied to a group of varieties, neither is it accurate when applied to a group of collections of bunt on a single variety which differs materially in its reaction to the different collections of bunt. Certain ones of the varieties in the present study do differ in this respect and this fact should be considered in interpreting the data. However, it is believed to have no important bearing on such conclusions as are arrived at herein.

EXPERIMENTAL RESULTS

In order to indicate the nature of the basic data used in the calculations, a skeleton table giving the results with 20 collections of bunt from the test with winter wheat varieties at Kearneysville, W. Va., in 1935, is presented in Table 1. Altogether 69 collections of bunt were included in this experiment, of which the 20 in the table are representative. The names of the varieties of wheat used are given in the first row at the top of the table and the designation of the collections of bunt in the first column on the left of the table. The two columns of figures under each variety name are the recorded percentages of bunt for each of the duplicated rows of each collection. At the bottom of the table are given the average percentage of bunt for all 69 collections for the first and second replications separately and also for each variety.

The average percentage of bunt for each variety of winter wheat for each of three locations and the standard error calculated separately for each variety are given in Table 2, and similar data for spring wheat at two locations are given in Table 3. The number of collections of bunt, which is also the number of pairs of duplicate rows on which the calculations for each variety are based, was 69 for Kearneysville, W. Va., 74 for winter wheat at Pullman, Wash., 48 for winter wheat at Bozeman, Mont., in 1934, 45 for spring wheat at Bozeman in 1933, and 55 for spring wheat at Pullman in 1935. The number of heads (N) counted per row is given in parentheses for each location.

It will be noted that the standard errors are very different for different varieties. Thus, at Kearneysville, the standard error for Turkey is nearly 9 times as great as that for Hohenheimer. At Pullman for winter wheat the largest standard error is more than 3 times the smallest; at Bozeman for winter wheat the ratio is more than 5, and for spring wheat 18; and at Pullman for spring wheat more than 2. It should require no additional data or argument to make it clear that the use of a generalized standard error derived by analysis of variance (or in any other way in which all data are pooled as in analysis of variance) to be applied to all varieties alike would lead to very erroneous conclusions.

TABLE 1.—*Relative infection in different varieties of wheat with 20 collections of bunt at Kearneysville, W. Va., in 1935.*

Bunt collection No.	Hybrid 128		Turkey		Min-turki		Oro		Ridit		Albit		Martin		Hohen-heimer		White Odessa		Hussar		Average percentage of bunt
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
1	86.6	80.7	8.3	6.5	79.1	72.8	0.0	0.9	6.3	3.9	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.5	0.6	17.5
2	76.4	95.2	89.0	84.3	90.6	84.3	2.5	3.6	8.7	2.2	92.4	90.6	18.4	16.0	0.0	1.4	97.5	98.1	81.0	74.9	55.4
3	94.9	93.3	3.3	6.0	87.9	75.4	1.5	0.0	6.0	0.7	93.7	90.1	84.5	64.8	0.0	0.0	97.8	94.4	0.0	0.7	44.8
4	91.0	91.7	81.7	87.2	92.0	82.6	1.5	6.3	4.1	3.1	14.0	4.5	0.0	3.0	0.0	0.0	75.9	84.7	0.0	0.7	36.3
5	83.7	90.2	7.5	2.4	60.6	80.9	0.6	1.6	3.9	3.6	4.2	3.2	0.0	2.2	2.4	2.5	0.7	0.0	0.0	0.7	17.7
6	88.9	92.2	5.6	7.4	52.5	39.4	1.1	0.0	2.2	0.0	0.0	0.0	5.0	0.6	0.0	0.0	0.0	0.0	1.6	0.0	14.9
7	97.5	97.9	13.7	9.0	55.6	44.3	0.0	0.8	2.0	1.8	0.0	0.9	1.4	0.8	7.1	0.0	2.0	1.9	0.0	0.0	16.9
7a	81.5	92.2	17.4	9.8	85.4	83.3	1.2	4.4	5.2	4.9	85.2	82.5	61.1	62.0	0.9	5.6	68.8	86.5	1.1	0.0	43.0
8	92.8	91.5	8.5	8.4	30.3	30.4	1.6	1.1	1.2	0.0	0.0	0.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
9	97.3	92.6	15.4	3.8	17.2	11.7	3.3	0.0	3.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	8.4	0.8	2.5	0.0	12.9
10	93.7	83.3	5.8	1.3	71.2	63.7	3.1	0.0	4.2	3.8	92.0	79.6	77.9	77.0	0.9	0.0	90.4	74.6	1.2	0.8	41.3
11	83.0	77.8	3.8	1.1	70.6	69.9	0.5	1.7	6.8	5.5	2.1	3.9	0.6	0.9	0.0	0.0	1.3	0.0	0.0	0.0	16.6
12	82.1	79.5	9.8	4.7	49.5	75.2	0.0	0.0	15.5	0.0	50.0	76.5	75.5	74.5	0.0	0.0	74.1	79.1	2.8	0.6	37.7
13	80.2	80.7	5.6	10.9	61.9	60.9	0.0	2.0	0.8	10.8	0.6	0.0	2.0	0.0	6.1	12.2	2.1	7.3	1.2	0.0	17.3
14	78.3	77.7	82.5	54.7	76.4	79.7	3.5	7.5	12.7	12.5	81.9	87.2	75.5	76.4	1.1	1.3	88.8	91.2	62.6	67.9	56.1
15	80.0	95.5	10.3	7.3	79.7	83.8	2.4	1.1	10.1	2.2	78.8	90.6	70.1	69.2	0.0	0.0	85.8	98.0	2.1	0.0	43.4
32	85.8	97.8	76.5	92.6	90.9	80.9	59.8	75.0	14.4	5.2	0.0	0.0	2.3	2.1	0.0	0.0	0.0	0.0	1.0	3.3	34.4
51	94.2	95.5	28.3	21.5	45.1	40.0	0.6	1.2	4.8	4.7	0.8	2.6	0.0	0.0	0.0	0.0	5.1	1.4	0.5	0.0	17.4
157	75.0	86.3	52.4	92.1	75.3	85.3	2.2	0.9	1.4	1.0	89.2	85.0	47.0	82.2	0.0	0.0	83.4	90.5	45.5	37.6	51.6
189	87.3	94.6	79.5	92.0	81.1	80.2	7.5	4.7	4.9	6.1	91.9	94.6	71.0	78.0	2.9	1.2	94.6	96.7	53.2	70.2	59.7
Average	87.2	90.7	43.7	46.2	76.9	77.9	3.7	4.4	4.5	4.2	28.5	29.1	23.0	22.5	0.4	0.8	33.3	33.4	10.9	10.6	
Grand average	89.0		45.0		77.4		4.1		4.4		28.8		22.8		0.6		33.4		10.8		

TABLE 2.—*Average percentage of bunt and standard errors for varieties of winter wheat at three locations.*

Variety	Kearneysville, W. Va., 1935 (N = 200)		Pullman, Wash., 1935 (N = 400)		Bozeman, Mont., 1934 (N = 300)	
	Average percentage of bunt, all collections	Standard error	Average percentage of bunt, all collections	Standard error	Average percentage of bunt, all collections	Standard error
Hybrid128	89.0	4.27	86.1	6.84	78.8	5.59
Minturki	77.4	6.98	—	—	—	—
Minhardi	—	—	—	—	60.9	4.59
Turkey	45.0	10.17	61.1	9.67	42.7	5.31
White Odessa	33.4	4.97	37.5	8.06	32.1	4.49
Albit	28.8	4.33	28.2	3.75	23.6	4.58
Martin	22.3	5.61	23.7	8.46	16.1	2.80
Hussar	10.8	4.41	8.6	5.89	10.3	2.82
Oro	4.1	2.71	6.1	2.45	4.4	2.53
Ridit	4.4	3.63	4.6	3.02	2.8	2.33
Hohenheimer	0.6	1.17	1.9	3.62	1.0	1.05

TABLE 3.—*Average percentage of bunt and standard errors for varieties of spring wheat at two locations.*

Variety	Bozeman, Mont., 1933 (N = 200)		Pullman, Wash., 1935 (N = 400)	
	Average percentage of bunt, all collections	Standard error	Average percentage of bunt, all collections	Standard error
Ulka	68.2	14.33	90.7	4.26
Mindum	33.0	9.78	—	—
Marquis	24.3	7.83	37.7	8.31
Vernal emmer	21.9	11.19	—	—
Ruby	11.5	5.43	34.7	9.62
Canus	—	—	25.6	6.59
Garnet	—	—	13.3	5.43
Golden Ball	1.8	1.15	—	—
Hope × Ceres	0.8	0.79	—	—

As would be expected there is definitely a relation between average percentage of bunt and standard error. In order to study this relation somewhat in detail, the data for individual pairs of rows were grouped in arbitrary classes according to the average percentage of bunt for each pair of rows, irrespective of variety of wheat and collection of bunt. Those in which no bunt appeared in either row were omitted, since it is clear that the standard error for such rows would be 0. The standard errors of the bunt classes were then calculated as before and are shown in Tables 4 and 5, together with other data to be explained later. A curvilinear relation is so clearly indicated as to invite comparison with the curve derived from the binomial in which $\sigma = \sqrt{\frac{p\,q}{N}}$, where p is the proportion or percentage of bunted heads,

q the proportion or percentage not bunted, and N the number of heads counted. However, as will appear later, the standard errors derived by this formula are much smaller than the observed, and in order to determine whether the forms of the observed and theoretical curves agree, it is necessary to multiply the binomial by a constant, say "a"; that is, $\sigma = a\sqrt{\frac{p\,q}{N}}$.

It is then necessary to choose that value of "a" for each set of data such that the resulting curve will agree most closely with the observed values.

Possibly the most satisfactory way to do this is to choose empirically successive values of "a" and calculate the corresponding values of σ until a value of "a" is found, such that the sum of the deviations equals 0. The labor, while rather tedious, is much less than might be expected. Equations for the curve for each of the five sets of experimental data have been calculated in this way, "a" being calculated to the third decimal, which is as accurate as the curves can be plotted. Each observed standard error was weighted according to the number of pairs of rows entering into its determination. The resulting curves are shown in Figs. 1 to 5, inclusive.

The observed standard error for each of the classes was compared with the theoretical standard error appropriate for the mean infection for each class, as determined by the formula stated above, $\sigma = a\sqrt{\frac{p\,q}{N}}$. The difference between the observed and the theoretical standard error may then be regarded as a measure of the degree to which the curves fit the data. These data for each test, together with the standard error of the differences, are given in Tables 4 and 5.

The agreement between the observed and theoretical curves is surprisingly good for the spring wheat at Pullman and the winter wheat at Bozeman. A considerable number of the discrepancies in the other three experiments are greater than can be explained by random variations, but nevertheless it is clear that the relation approaches that expressed by the theoretical curve.

A logical question is, Why cannot the binomial be applied directly to these data, or in other words, why has it been necessary to introduce the constant "a" in the binomial to make the observed values agree even reasonably well with the theoretical? The answer is that only a portion of the random error is taken into account, *viz.*, that due to simple sampling as the term is used by Yule (11). Bunt infection is greatly influenced by soil heterogeneity and a proper estimation of random errors must account for this source of variation as well.

It appears to be quite generally overlooked that the binomial is strictly applicable only to such problems as drawing marbles out of a bag, or tossing coins in which all the assumptions as to randomness, comparability, etc., are realized, and that it may not be at all reliable for biological data in which observed ratios are often materially influenced by environment. Yule (11, page 259) gives a useful discussion

TABLE 4.—*Comparison of observed and calculated standard errors for different classes of bunt in winter wheat.*

Bunt classes	Kearneysville, W. Va., 1935					Pullman, Wash., 1935					Bozeman, Mont., 1934				
	Number of pairs of rows	Average percentage of bunt	Standard error: Observed	Standard error: Calculated	Standard error: Difference	Number of pairs of rows	Average percentage of bunt	Standard error: Observed	Standard error: Calculated	Standard error: Difference	Number of pairs of rows	Average percentage of bunt	Standard error: Observed	Standard error: Calculated	Standard error: Difference
0.1– 2.5%	189	1.2	1.29	1.86	0.57±0.06	206	1.0	1.05	1.99	0.94±0.05	113	1.3	1.13	1.38	0.25±0.06
2.6– 5.0%	75	3.5	2.71	3.16	0.45±0.17	65	3.8	2.54	3.75	1.21±0.17	66	3.7	2.29	2.26	0.03±0.15
5.1– 10.0%	57	7.2	4.34	4.43	0.09±0.29	60	7.0	3.23	5.04	1.81±0.23	32	7.6	2.61	3.20	0.59±0.24
10.1– 20.0%	19	14.2	5.60	6.01	0.41±0.64	12	15.7	8.22	7.17	1.05±1.18	24	14.5	4.12	4.24	0.12±0.43
20.1– 30.0%	6	23.8	8.88	7.33	1.55±1.81	15	24.3	6.89	8.45	1.56±0.92	10	25.5	4.90	5.25	0.35±0.78
30.1– 40.0%	3	33.8	20.14	8.14	12.00±5.84	13	34.0	10.07	9.33	0.74±1.41	14	35.4	4.73	5.76	1.03±0.65
40.1– 50.0%	7	44.6	8.41	8.55	0.14±1.60	14	46.5	16.09	9.83	6.26±2.10	14	45.1	3.41	6.00	2.59±0.47
50.1– 60.0%	6	54.4	23.69	8.57	15.12±4.83	14	54.7	25.18	9.81	15.37±3.40	16	56.4	5.73	5.98	0.25±0.73
60.1– 70.0%	17	65.2	12.57	8.19	4.38±1.52	21	65.7	12.69	9.35	3.34±1.41	37	65.1	7.77	5.74	2.03±0.63
70.1– 80.0%	52	75.9	9.00	7.36	1.64±0.65	24	79.7	13.59	7.92	5.67±1.40	53	75.9	5.45	5.15	0.30±0.39
80.1– 90.0%	116	87.4	5.25	5.71	0.46±0.27	101	85.8	6.18	6.87	0.69±0.33	39	84.7	4.81	4.34	0.47±0.39
90.1– 95.0%	38	92.4	3.43	4.57	1.14±0.29	36	92.4	3.70	5.21	1.51±0.34	1	93.0	2.83	3.07	0.24±1.40
95.1– 97.5%	10	95.9	2.21	3.42	1.21±0.36	5	96.9	3.62	3.41	0.21±0.83	—	—	—	—	—
97.6–100.0%	3	97.8	0.09	2.54	2.45±0.06	—	—	—	—	—	—	—	—	—	—

TABLE 5.—*Comparison of observed and calculated standard errors for different classes of bunt in spring wheat.*

Bunt classes	Bozeman, Mont., 1933					Pullman, Wash., 1935				
	Number of pairs of rows	Average percentage of bunt	Standard error			Number of pairs of rows	Average percentage of bunt	Standard error		
			Observed	Calculated	Difference			Observed	Calculated	Difference
0.1– 2.5%	94	0.6	0.56	1.72	1.16±0.06	23	0.9	0.95	1.66	0.71±0.12
2.6– 5.0%	6	4.1	1.66	4.37	2.71±0.26	8	3.7	3.42	3.42	0.00±0.62
5.1–10.0%	27	7.8	4.06	5.92	1.86±0.45	12	7.8	4.65	4.83	0.18±0.79
10.1–20.0%	38	15.3	8.13	7.96	0.17±0.70	37	15.4	6.61	6.50	0.11±0.59
20.1–30.0%	53	25.7	9.27	9.66	0.39±0.70	26	25.8	6.97	7.87	0.90±0.77
30.1–40.0%	26	34.2	11.21	10.48	0.73±1.16	34	36.2	10.29	8.65	1.64±0.89
40.1–50.0%	19	45.2	13.56	11.00	2.56±1.60	38	44.7	9.45	8.95	0.50±0.90
50.1–60.0%	10	56.3	17.55	10.96	6.59±2.79	19	55.0	9.01	8.96	0.05±1.10
60.1–70.0%	14	67.0	12.44	10.39	2.05±1.70	13	64.0	10.51	8.64	1.87±1.51
70.1–80.0%	13	74.2	14.69	9.67	5.02±2.06	2	76.3	2.12	7.66	5.54±0.80
80.1–90.0%	8	85.7	4.06	7.74	3.68±0.77	6	86.9	4.37	6.07	1.70±0.90
90.1–95.0%	1	91.5	2.12	6.16	4.04±1.07	29	93.3	3.71	4.51	0.80±0.36
95.1–97.5%	—	—	—	—	—	15	95.9	2.74	3.56	0.82±0.36
97.6–100.0%	—	—	—	—	—	1	98.0	1.91	2.56	0.65±0.97

of these limitations. For the same reason, chi-square, as ordinarily used, is not applicable to the problem considered here. The extent to which heterogeneity (principally soil) affected the data reported

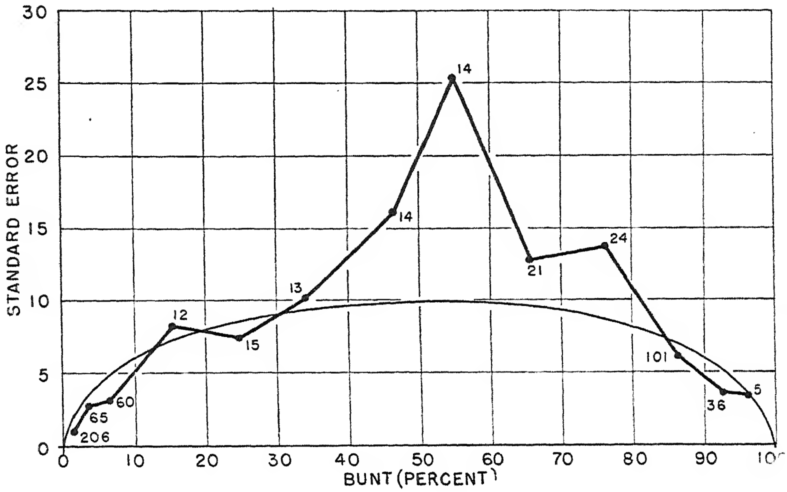

FIG. 1.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for winter wheat at Pullman, Wash., 1935. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form. $\sigma = 3.940\sqrt{\frac{p\,q.}{N}}$ N = 400.

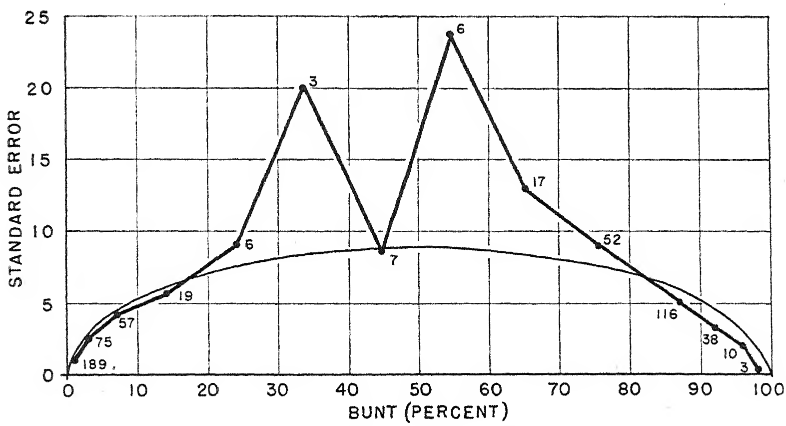

FIG. 2.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for winter wheat at Kearneysville, W. Va., 1935. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 2.432\sqrt{\frac{p\,q.}{N}}$ N = 200.

herein may be realized from the fact that in no one of the five experiments does simple sampling account for more than one-half of the standard error, or one-fourth of the variance due to total random variation. In one case (winter wheat at Pullman, Wash.) it accounts for only one-fourth of the standard error, or one-sixteenth of the variance.

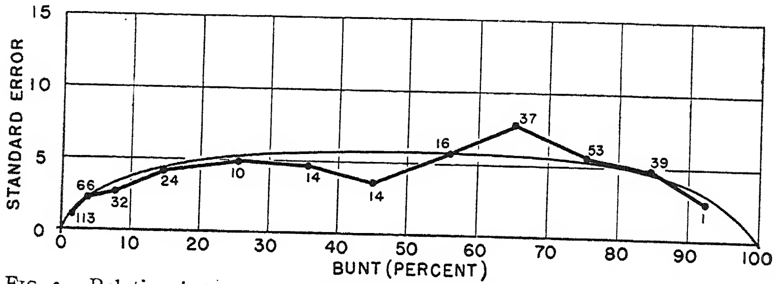

FIG. 3.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for winter wheat at Bozeman, Mont,. 1934. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 2.096 \sqrt{\frac{p\,q.}{N}}$ N = 300.

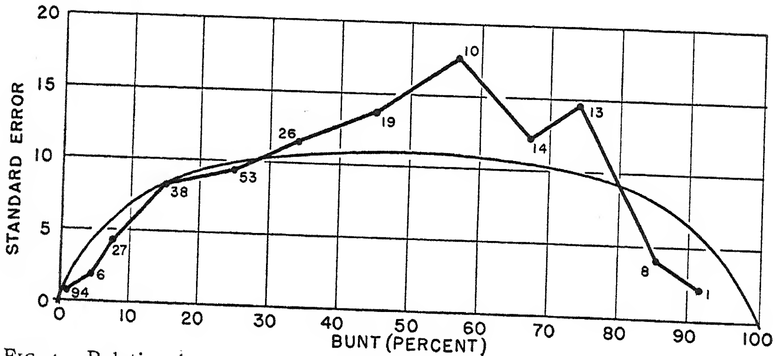

FIG. 4.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for spring wheat at Bozeman, Mont., 1933. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 3.125 \sqrt{\frac{p\,q.}{N}}$ N = 200.

Another question relates to the reason or reasons for the departures from the fitted curves as noted above. They are not known with certainty but some of the possibilities seem to merit consideration. The different varieties of wheat are represented very unequally in the different bunt classes (Tables 4 and 5). This, of course, follows from the fact that the varieties differed greatly in their susceptibility to bunt as shown in Tables 2 and 3. Thus, for example, at Kearneysville, the class 0.1 to 2.5% is made up almost entirely of Hohenheimer

and Oro, with a few pairs of rows each from Hussar, White Odessa, Martin, Albit, and Ridit. Neither Minturki, Turkey, nor Hybrid 128 is represented. On the contrary, the classes 70.1 to 80; 80.1 to 90; 90.1 to 95; and 95.1 to 97.4, for spring wheat at Pullman are made up entirely of Ulka. It follows that if there is an inherent tendency for one variety to be more or less variable than another with reference to any collection of bunt, the probability of infection for both varieties being the same, the observed standard errors, as reported in this paper, would be expected to deviate from the theoretical.

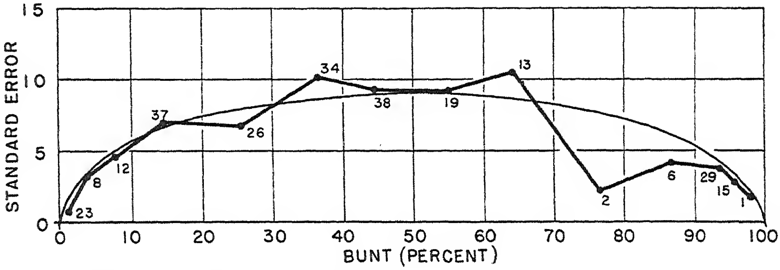

FIG. 5.—Relation between percentage of bunt (abscissa) and standard error (ordinate) for spring wheat at Pullman, Wash., 1935. The figures represent the number of pairs of rows on which the calculations are based. The smoothed curve is the best fitting of the general form $\sigma = 3.600\sqrt{\frac{pq}{N}}$. $N = 400$.

In all cases the percentage of bunt is expressed as a percentage of heads rather than of plants. This means that there is a certain but undetermined degree of correlation in the data which, as Yule points out (11, page 287), affects the standard error. Moreover, the effect probably is not the same for all varieties because of differences in rate of tillering. Heads from late tillers are more likely to be bunted than those from early tillers, and it is possible that the varieties included in the study differed in tiller development. To what extent these various circumstances may have affected the standard errors is not known. An attempt has been made to study them, but the result is far from conclusive because of the difficulty of securing enough comparisons between varieties at the same level of infection. Data bearing on this point are presented in Table 6. This table includes a tabulation of the standard errors for different varieties for the same bunt classes in so far as such data are available, except that no data are included where the number of pairs of rows entering into the calculation is less than 10.

Pairs of varieties in which the difference between their standard errors is approximately as great as or greater than twice the standard error of the difference are tabulated in Table 7.

It will be noted that standard errors of a number of varieties at the same level of bunt infection appear to differ significantly from those of others. However, the differences are in no case very great, the number of cases where there are such differences is rather few,

TABLE 6.—*Comparison of standard errors for different varieties of wheat at similar levels of infection.*

Bunt class and variety	Number of pairs of rows	Average percentage of bunt	Standard error
Pullman, Wash., Winter Wheat			
0.1–2.5%:			
Albit	20	0.9	0.81±0.13
Oro	27	1.6	1.14±0.16
Ridit	24	1.5	1.11±0.16
Hussar	45	0.8	0.73±0.08
White Odessa	27	0.7	0.74±0.10
Hohenheimer	26	0.8	1.50±0.21
Martin	37	1.0	0.91±0.11
2.6–5.0%:			
Ridit	25	3.8	2.09±0.30
Oro	17	3.8	1.56±0.27
5.1–10.0%:			
Ridit	21	7.2	4.00±0.62
Oro	27	6.7	2.48±0.34
80.1–90%:			
Hybrid 128	36	86.7	6.62±0.78
Turkey	24	86.0	6.79±0.98
Albit	19	85.3	6.11±0.99
White Odessa	15	85.4	4.54±0.83
Pullman, Wash., Spring Wheat			
40.1–50%:			
Marquis	13	44.8	9.17±1.80
Ruby	19	44.0	10.47±1.70
Bozeman, Mont., Spring Wheat			
10.1–20.0%:			
Vernal emmer	13	16.2	8.63±1.69
Ruby	14	14.1	6.38±1.21
20.1–30.0%:			
Vernal emmer	18	24.7	10.75±1.79
Mindum	16	26.2	11.00±1.95
Marquis	12	25.7	5.04±1.03
Kearneysville, W. Va., Winter Wheat			
0.1–2.5%:			
Ridit	18	1.7	1.72±0.29
White Odessa	20	1.1	1.44±0.23
Hohenheimer	17	1.3	1.34±0.23
Oro	31	1.4	1.43±0.18
Albit	25	0.9	—
Martin	35	1.3	—
Hussar	42	1.0	1.00±0.11
70.1–80.0%:			
Turkey	13	74.2	11.98±2.35
Minturki	20	76.1	8.40±1.33
Martin	11	76.8	6.53±1.39
Bozeman, Mont., Winter Wheat			
0.1–2.5%:			
Oro	23	1.7	1.31±0.19
Ridit	24	1.3	1.30±0.19
Hohenheimer	25	0.9	1.09±0.15

TABLE 7.—*Pairs of varieties in which differences in standard errors appear to be significant or nearly so.*

Variety	Bunt class	Difference in standard errors
Pullman winter wheat:		
Hohenheimer—Hussar	0.1– 2.5%	0.77 ± 0.22
Hohenheimer—White Odessa	0.1– 2.5%	0.76 ± 0.23
Hohenheimer—Albit	0.1– 2.5%	0.69 ± 0.25
Oro—Hussar	0.1– 2.5%	0.41 ± 0.18
Oro—White Odessa	0.1– 2.5%	0.40 ± 0.19
Ridit—Oro	5.1–10%	1.52 ± 0.71
Turkey—White Odessa	80.1–90%	2.25 ± 1.28
Bozeman spring wheat:		
Vernal emmer—Marquis	20.1–30%	5.71 ± 2.07
Mindum—Marquis	20.1–30%	5.96 ± 2.21
Kearneysville:		
Ridit—Hussar	0.1– 2.5%	0.72 ± 0.31
Turkey—Martin	70.1–80.0%	5.45 ± 2.73

and as pointed out by Tippett (9, page 54), differences somewhat greater than twice the standard error are necessary as indicative of significance where specific comparisons of two varieties of several possible comparisons are selected for consideration. Altogether it would seem that while the possibility of varietal differences must be considered, it is quite clear that in the present case they are hardly sufficient to account for the difference between the observed and the theoretical curves.

It will be noted that the principal deviations between the observational and theoretical curves occur in the intermediate bunt classes. In fact, if the classes between 30.1 and 70% at Kearneysville, the 50.1 to 60% class for Pullman, and classes between 60.1 and 80% for spring wheat at Bozeman be disregarded for the time being, theoretical curves may be drawn which will fit the remaining classes in a very satisfactory manner.

What appears to be a satisfactory explanation for the discrepancies in the intermediate classes may be arrived at as follows: If experiments such as those under consideration were conducted on a perfectly homogeneous field, it would be expected that the total random error would be accounted for by simple sampling. It therefore seems reasonable to assume that the discrepancies referred to are an expression of the lack of homogeneity of the experimental conditions. Lack of homogeneity would have no effect on the variability of a variety of wheat immune from bunt, since there would be no variation. Its effect would be small on a highly resistant variety. The effect would also be small for any pairs of rows of a very susceptible variety falling into the higher bunt classes; otherwise they would not fall in those classes. No such limitations, however, apply to the intermediate classes. The net result would appear to be standard errors in excess of the theoretical in those classes near and above the 50% level of infection, which agrees with the observations. Whether this is the true explanation cannot be determined with certainty from the available data.

There does not, however, appear to be anything in them to the contrary.

The arbitrary grouping into classes according to the average percentage of bunt in the pairs of rows may possibly have had a slight effect. Such grouping would tend to reduce the standard error for those with a very small or a very high percentage of bunt as compared with what would likely be observed for a large number of rows of a homogeneous variety which had either a very low or a very high percentage of bunt. The effect, however, would be small and it is believed has been a negligible factor in the present study.

The distribution of smutted rows is not always normal and this appears especially likely to be the case for highly resistant or near immune varieties. Whether this has had anything to do with the discrepancies between the observed and theoretical curves is not known. It does have a bearing on the accuracy or reliability of generalized estimates of error.

The results, as a whole, raise a number of questions to which the available data provide no definite answer. One is whether any estimate of random errors sufficiently reliable to be of use can be calculated for experiments such as those under discussion in which the number of replications is very few and in which a generalized standard error calculated from data pooled without reference to infection is not valid.

Grouping the data according to percentage of bunt and calculating separate standard errors for each group, such as was done in the present study, are naturally suggested. The smaller the range for each group and the fewer the varieties or other sources of heterogeneity in each group, the more accurate is the final result likely to be. Curves may be fitted to the observed standard errors, as already described, and these may then be used to estimate the standard error for any level of bunt infection. When the calculated curve fits the observed standard errors reasonably well throughout the entire range of bunt infection, this method should prove satisfactory.

For situations such as those for winter wheat at Kearneysville and Pullman and for spring wheat at Bozeman, it would appear that any standard errors calculated from the theoretical curve will be approximations only. It would be possible, however, to fit curves to portions of the range in which the fit is good, and these may then be used for estimating standard errors within this range. Thus, at Bozeman, a curve fitted for the range from 0 to 35% bunt would be expected to give reliable estimates of standard error within this range. A similar procedure would appear to be satisfactory for the ranges from 0 to 25% and from 85% to 100% bunt at Kearneysville, and for the range 0 to 35% for winter wheat at Pullman. For other portions of the range for these particular experiments any estimates of random error that might be derived by any known method would be highly speculative.

This method of estimating the random error by grouping is of course somewhat empirical since the results depend to some extent on the size of the bunt classes. This involves no precedent, however, and it appears to be much more reliable than those in current use. It would appear that there is abundant justification for using it until a better one is devised.

Collins and Longley (3) have pointed out that the ratio of the standard errors for various levels of infection to the standard error for 50% infection is given by the expression $\sqrt{\frac{50}{p\,q}}$. Collins[4] has suggested that variances can be equalized by multiplying those for each level of infection by the ratio $\frac{\bar{p}\,\bar{q}}{p\,q}$ where $\bar{p}$ is the average percentage infection, $\bar{q}$ the average not infected, and p and q are the percentage infected and not infected for any given case. The variances may then be averaged to secure a generalized estimate of error. This must then, of course, be multiplied by $\frac{p\,q}{\bar{p}\,\bar{q}}$ to secure the appropriate value applicable to any given degree of infection. This method accomplishes substantially the same result as grouping the data noted above and of course depends for validity on the assumption that the relation between standard error and infection is that of the fitted curve.

Perhaps it is of most importance for the reader to realize that no known method of calculation will always assure a strictly accurate and reliable estimate of standard error from grouped data such as those considered herein. Consequently, such estimates should be considered as rough approximations only until the contrary is proved. If such approximate estimates of random error are considered too inaccurate, it would seem that the only recourse is a more elaborate experiment in which the number of replications is sufficient to afford at least a reasonably reliable measure of random variation for each variable.

Another question of considerable interest and importance is whether the use of generalized standard errors may not lead to erroneous conclusions in experiments other than those involving bunt in wheat. Aamodt and Platt (1), for example, have derived a single error term by analysis of variance for loose smut infection in varieties of oats. Allison (2) has followed a similar procedure for smut in barley and Youden (10) for tobacco mosaic. Data presented by Hoppe and Holbert (6) show very clearly that generalized errors, as usually derived, could not logically be applied to kernel-rot data in corn if the range in infection is very great.

There is also considerable doubt as to whether the use of generalized standard errors for yield and other quantitative data may always be justified. Data suitable for critical studies of these relations are very meager or do not exist, but enough has been accumulated to convince the writer that caution is necessary if serious errors are to be avoided. It appears that significant differences between the variances of different varieties of small grain, for example, are especially likely to be found when some varieties yield near 0 and others produce moderate or high yields. The variance for yield of roots of certain perennial weeds has been found, in general, to be materially less on continuously cultivated plats, where the yield is low, than on uncultivated plats when the yield is high. Other examples might be cited.

[4]Orally.

Certainly, as previously mentioned, the practice sometimes followed and recommended of including data from different stations and different seasons in a single analysis of variance set-up and in which a single error term is applied to all stations and seasons alike cannot be justified as a general procedure, though it may not lead to erroneous conclusions in particular cases. Instances in which it can be shown that significant differences in variance occur within a single experiment for one season at one place apparently are not common, and hence it should not be inferred that generalized standard errors are never valid or useful. The point it is intended to emphasize is that caution is essential and that the possibility of significant differences should always be considered.

SUMMARY

Data are presented from tests to determine differences in bunt infection in wheat varieties which show that estimating random variation by analysis of variance, or by any method in which all varieties are grouped together irrespective of bunt infection, may be seriously in error when varieties are included which differ materially in infection. The binomial and chi-square determinations, as generally used for estimating statistically significant differences, also are unreliable for bunt resistance tests, for the reason they take into account only the random variation due to simple sampling and not that due to heterogeneity in environment (principally soil differences).

The data suggest that estimates of random error commonly employed in similar experiments dealing with other diseases of plants, or with certain variables other than plant diseases, also may be in error.

In bunt tests with wheat it was found, as would be expected, that the standard error is to a considerable degree a function of the infection, approaching 0 at 0 and 100% infection and reaching a maximum at or near the 50% level of infection. The form of the curve is similar to that expressed by the binomial. Introducing a constant into the binomial formula to account for random errors other than those due to simple sampling makes it possible to predict the standard errors with a fair degree of accuracy when the observed standard error for any given level of infection is known.

A method of estimating standard errors for grouped bunt data is suggested, making use of the relation between standard error and bunt infection. This method is not regarded as strictly accurate since it assumes like standard errors for all varieties at the same level of infection. It is not known that this assumption is always realized in practice; however, the method is believed to be more reliable than those generally employed.

LITERATURE CITED

1. Aamodt, O. S., and Platt, A. W. Varietal testing for the reaction of oats to diseases, especially covered smut. Can. Jour. Res., 14:425–437. 1936.
2. Allison, Clyde C. Studies on the genetics of smuts of barley and oats in relation to pathogenicity. Minn. Agr. Exp. Sta. Tech. Bul. 119. 1937.

3. COLLINS, G. N., and LONGLEY, A. E. A tetraploid hybrid of maize and perennial teosinte. Jour. Agr. Res., 50:123–133. 1935.
4. HAYES, H. K. Controlling experimental error in nursery trials. Jour. Amer. Soc. Agron., 15:177–192. 1923.
5. ——————, and IMMER, F. R. A study of probable error methods in field experiments. Sci. Agr., 8:345–352. 1928.
6. HOPPE, P. E., and HOLBERT, J. R. Methods used in the determination of relative amounts of ear rot in dent corn. Jour. Amer. Soc. Agron., 28: 810–819. 1936.
7. IMMER, F. R. A study of the association between mean yields and standard deviations of varieties tested in replicated yield trials. Jour. Amer. Soc. Agron., 28:24–27. 1936.
8. RODENHISER, H. A., and HOLTON, C. S. Physiologic races of *tilletia tritici* and *t. levis*. Jour. Agr. Res., 55:483–496. 1937.
9. TIPPETT, L. H. C. The Methods of Statistics. London: Williams and Norgate Ltd.
10. YOUDEN, W. J. Use of incomplete block replications in estimating tobacco-mosaic virus. Contr. Boyce Thompson Inst. Plant Res., 9:41–48. 1937.
11. YULE, G. U. An Introduction to the Theory of Statistics. London: Chas. Griffin and Co. Ltd. 1922.

SELENIUM AND TENMARQ WHEAT[1]

ALFRED T. PERKINS AND H. H. KING[2]

CONSIDERABLE interest has recently been aroused in the toxicity of selenium to plant and animal life. The work of the U. S. Dept. of Agriculture has been outstanding in this regard. Selenium has been found in parts of Kansas, and the data reported here have been collected as a result of general interest in selenium and elements of minor importance to plant growth. The initial objective in this problem was to determine the toxicity of selenium to Tenmarq wheat grown in Derby soil in the greenhouse. Tenmarq is a winter wheat having many desirable characteristics.

Glazed porcelain pots of 2-quart capacity were filled with 1,750 grams of well-mixed Derby soil and treated with various amounts of selenium added as $Na_2SeO_4.10H_2O$. The amount of selenium added varied from 0 to 100.00 p. p. m. of dry soil. The exact applications are outlined in Table 1.

TABLE 1.—*Chloratic conditions and germination of Tenmarq wheat as affected by various selenium applications, wheat sown October 3, 1935.*

Pot No.	Selenium added, p.p.m.	Ave. No. sprouts per pot on		Selenium injury on Oct. 14
		Oct. 5	Oct. 8	
1–2	0.0000	Not seeded	Not seeded	No wheat
3–11	0.0000	5	10–	None
12–20	0.4096	7	10–	None noticeable
21–29	1.0240	7	10–	A little chlorosis at base of some primary leaves
30–38	2.5600	7	10–	Chlorosis and slight rose coloration from base of primary leaves and yellow color at leaf tips
39–47	6.4000	5	10–	As above
48–56	16.0000	5	8	Some chlorosis, considerable leaf yellowing, and gummy exudate on leaf tips
57–64	40.0000	2	4	Scant growth and as above
65–72	100.0000	1	1	No growth

Nine pots were prepared for each selenium application as well as nine pots with no selenium and two unplanted check pots with no selenium. Twelve seeds were planted in each pot on October 3, 1935, and growth started by adding 300 cc. of water to each pot. Three times a week the pots were weighed and sufficient water added to restore them to their original weight.

Germination, early chlorotic conditions, and other data are given in Table 1. From the data in Table 1 it seems that small amounts of selenium somewhat encourage early germination as on October 5 only an average of five seeds each had germinated in pots receiving

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no selenium, while in pots receiving the lighter applications of selenium an average of seven seeds each had germinated. Heavier selenium applications, however, caused a decrease in germination. On October 8, 0 and slight selenium applications showed the same degree of germination as applications up to and including 6.4 p.p.m.

The data recorded in Tables 2 and 3 give an indication of the plant growth by giving the height of the seedlings and mature plants, the amount of water consumed per pot above that consumed by the blank pots (Nos. 1 and 2), and the harvest weight of the wheat. It appears that early growth of the wheat was aided by a light application of selenium. Germination was encouraged and the height of the week-old plants grown in soil with 0.4096 p.p.m. of selenium was slightly greater than that of the plants grown in selenium-free soil. It is apparent, however, that the early physiological activity of the plants was decreased by applications of selenium. Up until February the water consumed by the plants was inversely related to the amount of selenium applied. At this stage of growth, when the wheat would normally be in the winter rest stage, the general appearance of the wheat, height of plants, etc., varied indirectly as the amount of selenium applied.

TABLE 2.—*Height of wheat plants and dry weight at maturity as affected by applications of selenium, wheat sown October 3, 1935.*

Pot No.	Selenium application, p.p.m.	Height of wheat in inches		Dry weight at harvest, grams	Mature seeds found
		Oct. 15, 1935	May 2, 1936		
1–2	0	Blank	Blank	Blank	Blank
3–11	0	5½	12	15	Yes
12–20	0.4096	5¾	17	18	Yes
21–29	1.0240	5¼	20	30	Yes
30–38	2.5600	4½	19	23	Yes
39–47	6.4000	4¼	*	*	No
48–56	16.0000	3	*	*	No
57–64	40.0000	1¼	*	*	No
65–72	100.0000	¼	*	*	No

*No growth with this and increasing treatments.

The check pots with no selenium appeared the best, and growth decreased as the amount of selenium applied increased. The pots of wheat were kept in the greenhouse all winter, and the wheat was not permitted to go into the full dormant stage. As the activity of the plants increased in February, the growth of the wheat seemed to reverse itself; the pots receiving selenium applications began consuming significantly more water and growing faster. A photograph (Fig. 1) taken on March 3, 1936, shows how selenium stimulated the spring growth of Tenmarq wheat. Pot No. 1 received no selenium; No. 2, 0.4096 p.p.m.; No. 3, 1.0240 p.p.m.; and No. 4, 2.5600 p.p.m. All heavier selenium treatments killed the wheat. The final harvest weights of the wheat indicate that the best growth was obtained when the soil was treated with 1 p.p.m. of selenium. The increased growth of wheat resulting from small applications of selenium checks with the

TABLE 3.—*Water consumption as affected by applications of selenium, wheat sown October 3, 1935.*

Pot No.	Water in cc lost during 2-day periods ending									Total amount of water lost, cc
	Oct. 15, '35	Oct. 26, '35	Nov. 23, '35	Dec. 21, '35	Jan. 23, '36	Feb. 24, '36	Mar. 19, '36	Apr. 21, '36	May 2, '36	
1–2	Blank	Blank	Blank	Blank	Blank	Blank	Blank	Blank	Blank	Blank
3–11	11	24	24	35	6	17	35	35	7	1,522
12–20	11	24	20	37	4	27	50	40	14	2,003
21–29	10	18	16	31	2	37	70	65	16	2,274
30–38	6	15	10	10	0	21	65	70	12	1,661
39–47	7	11	4	3	Dead	Dead	Dead	Dead	Dead	231
48–56	6	10	3	Dead	Dead	Dead	Dead	Dead	Dead	118
57–64	3	Dead	Dead	Dead	Dead	Dead	Dead	Dead	Dead	60
65–72	0	Dead	Dead	Dead	Dead	Dead	Dead	Dead	Dead	23

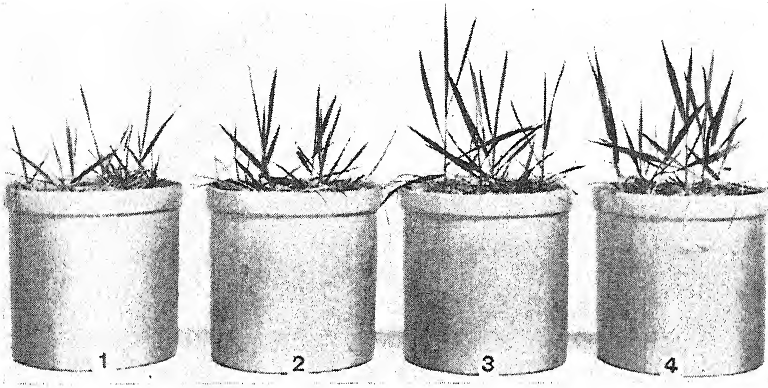

FIG. 1.—Pot 1, no selenium; pot 2, 0.0496 p. p. m. selenium; pot 3, 1.0240 p. p. m. selenium; pot 4, 2.5600 p. p. m. selenium.

work of Levine.[3] A bibliography of 23 references on selenium has been compiled by Willis.[4]

CONCLUSIONS

When Tenmarq wheat was grown in the greenhouse on Derby soil and not allowed full winter dormancy, the following observations were recorded:

1. Light applications of selenium aided early germination.
2. Early growth (fall) was depressed by selenium applications, the degree of depression varying directly with the amount of selenium applied.
3. Applications of selenium of 6 p.p.m. and more killed the wheat. The heavier the application, the earlier death resulted.
4. Applications of selenium up to 2.5 p.p.m. stimulated the spring growth and harvest weight.

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[3]LEVINE, V. E. Amer. Jour. Bot., 12:82–90. 1925.

[4]WILLIS, L. G. Bibliography of The Minor Elements. Ed. 2. Chilean Nitrate Educational Bureau.

A POSSIBLE METHOD FOR LOCATING FAVORABLE GENES IN MAIZE[1]

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PRESENT-DAY methods of corn improvement involve the isolation of inbred lines through self-fertilization and selection. These inbred strains are subsequently intercrossed and some, though not all, hybrid combinations are superior in vigor to the open-pollinated varieties from which the inbred lines were derived. Practically all crosses are greatly superior to the vigor of the inbred parents. The theoretical foundations for the increased vigor obtained by these empirical methods have never been completely established. The assumption is that open-pollinated varieties of corn are heterozygous for many pairs of genes, the recessive alleles of which have in general less favorable effects upon viability and vigor than their dominant alleles. Different varieties and different individuals of the same variety may carry different recessive genes.

Under field conditions, cross-pollination rather than self-pollination usually occurs, hence the recessives tend to be suppressed by their dominant alleles. The occurrence of some of the barren and weak plants in a varietal population can however be attributed to the homozygosity of less favorable recessive genes. Self-fertilization permits the manifestation of recessives, while intercrossing of inbred strains restores the hybrid vigor, provided the two inbred lines possess different favorable dominant genes. One inbred line may carry a less favorable recessive a and a more favorable dominant gene (or genes) B and a second inbred strain may possess dominant A and recessive b. The hybrid between the two will carry both dominant A and B and consequently will be superior in vigor to the two parents. It may be further assumed that, on the whole, those hybrid combinations resulting from the combining of inbred strains carrying many different favorable dominant genes will have more vigor than those hybrids from lines combining a small number of different dominants.

Richey and Sprague (4)[3] have presented data which argue strongly for the validity of the dominant favorable gene hypothesis as the cause of hybrid vigor, but they do not exclude the possibility that their data might have resulted, in part at least, from a kind of physiological stimulation caused by bringing together gametes with unlike germ plasms. However that may be, it is reasonable to assume that a method which would permit an exact analysis of the genetic constitution of separate chromosomes might be of practical value as well as having a direct bearing on the correctness of the two possible interpretations of the effects of inbreeding and hybrid vigor given by Richey and Sprague (4). On the dominant favorable gene hypothesis it should

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[3]Figures in parenthesis refer to "Literature Cited", p. 674.

be possible through such an analysis to demonstrate, for example, that chromosome 7 of one inbred strain carries a dominant favorable gene (or genes) not found in chromosome 7 of another inbred line, while the latter, on the other hand, may have a group of favorable dominants in chromosome 3 which are not present in chromosome 3 of the first inbred.

Theoretically, it should be possible to find those chromosomes in the different inbred lines that carry the most desirable assemblages of favorable dominant genes for yield or other agronomic characters. Such information might, conceivably, be of considerable assistance to the corn breeder. At any rate, it should provide a more enlightened foundation for the breeding program. Certain results recently obtained in an organism very different from maize, namely, the fly, *Drosophila pseudoobscura*, are of interest in this connection, as pointing towards the working out of such breeding methods (5, 1, 2).

Samples of natural populations of *Drosophila pseudoobscura* were taken in various localities where this species occurs, especially on certain mountain ranges in California and Nevada. Individual flies coming from the same as well as from different samples proved to be scarcely if at all different in appearance from each other. And yet, a tremendous genetic diversity was found concealed behind this apparent external uniformity. The following experimental procedure was employed by Dobzhansky and Queal (2) in these studies. Individual males collected in their habitats were crossed to females homozygous for the third chromosome recessives orange (*or*) and purple (*pr*). These mutant genes serve as markers enabling one to follow the third chromosomes of the wild males in inheritance. Single males were taken from the F_1 generation of each cross and outcrossed to females carrying in one of their third chromosomes the recessives *or*, *pr*, and the dominants Blade (*Bl*) and Scute (*Sc*). In the next generation females and males showing the characters *Bl* and *Sc* but not those of *or* and *pr* were selected and intercrossed. In the offspring, some individuals must be homozygous for *or*, *Bl*, *Sc*, and *pr*; since the gene *Bl* has a lethal effect when homozygous, these individuals die (Fig. 1). Among the survivors, one-third or 33.3%, are homozygous for a third chromosome derived from the wild ancestor and are expected to be normal, or wild-type, in appearance. Two-thirds or 66.7% of the individuals carry one normal third chromosome and one *or Bl Sc pr* chromosome. They will show the characters *Bl* and *Sc*.

The above theoretical expectation is, however, far from always realized in practice. Among 849 crosses of this kind executed by Dobzhansky and Queal (2) nearly 12% produced no wild-type offspring. The only possible explanation of this fact is that about 12% of the cultures studied carried a third chromosome having a recessive lethal gene or genes which produce no visible external effects when heterozygous. Another 3% of the cultures had between 0% and 14% of wild-type flies instead of the expected 33.3%. The third chromosomes involved in such crosses carry recessive semi-lethal genes that reduce the viability of the homozygotes far below normal. The remainder of the cultures contained between 18% and 50% of wild-type individuals. A further analysis, the details of which need not be dis-

cussed here, has shown that the deviations from the expected ratios observed in these cultures are significant and are due to the presence of genes in at least 39% of the third chromosomes encountered in natural populations which produce slight but perceptible reductions of viability in homozygous condition. Finally, a small minority of the wild third chromosomes, probably not much more than 2%, seem to carry genetic factors that improve the viability of the flies, at least under the environmental conditions in which the flies are raised in laboratory experiments.

We may conclude that no less than 54% of the third chromosomes found in natural populations of *Drosophila pseudoobscura* contain recessive genes that are deleterious and only about 2% of the tested chromosomes carry genes favorable for viability. Now, the species *D. pseudoobscura* has five pairs of chromosomes. One of them, the sex determining X-chromosome, is in a somewhat special condition; the others may be expected to be populated with unfavorable viability genes to an extent comparable to that observed in the third chromosome. Indeed, preliminary experiments of Sturtevant (5) suggest that this is the case for the second chromosome. It follows that flies free from hidden unfavorable viability genes must be rare in natural populations; reduction of viability following inbreeding is, consequently, not unexpected. Yet, as stated above, a few of the chromosomes seem to carry superior genes. If an analogous situation obtains not only in wild races of *Drosophila* but in domestic plants and animals as well, the importance of it from the breeder's standpoint requires no comment.

In discussing the genetic procedure used for the detection of the viability genes in *Drosophila* we have, up to now, deliberately refrained from mentioning one of its essential features, which must be carefully thought through if a similar technic is to be developed for corn investigations. The crosses represented schematically in Fig. 1 are designed to obtain individuals known to carry a given type of third chromosome in duplicate, for only under such condition can the recessives borne in this chromosome manifest themselves. It is necessary, therefore, that the chromosome in question be transmitted intact from generation to generation in the whole series of crosses. Yet this chromosome runs the risk of being broken up by crossing-over with other types of third chromosomes. To avoid, or at least to diminish, this risk, the chromosomes containing the gene markers are made to carry inverted sections that suppress most or all crossing-over. A brief explanation of the rôle of inverted sections may be useful here for the sake of those not fully conversant with the intricacies of modern cytogenetics.

Let the usual or normal gene order in a chromosome be represented as *ABCDEFG*; if the portion of the chromosome containing the block of genes from *B* to *E* is inverted, i.e., rotated by 180 degrees, the gene order becomes *AEDCBFG*. In individuals carrying one chromosome with the normal gene order and one with the inverted order, crossing-over can occur in the inverted region provided meiotic pairing takes place. Fig. 2 shows, however, that single crossovers within the inversion give rise to chromosomes deficient for some genes and carrying

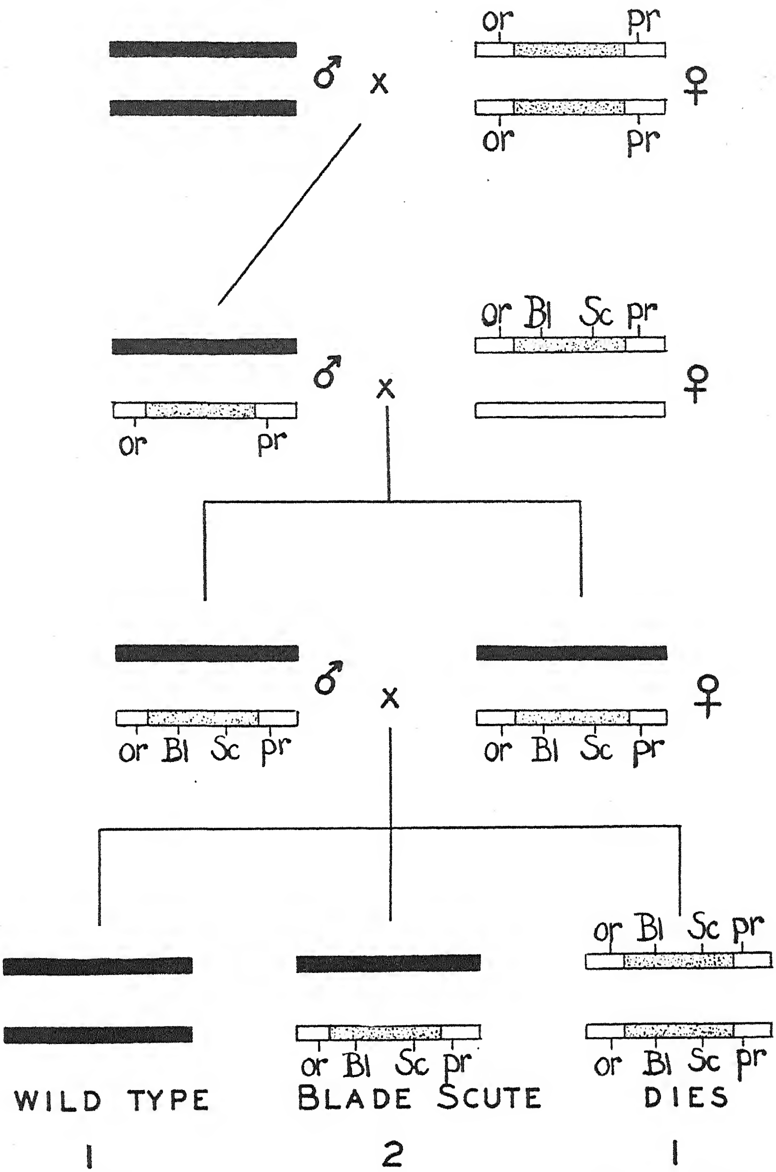

FIG. 1.—Experimental procedure for the detection of the genetic variability in the third chromosome of *Drosophila pseudoobscura*. Chromosomes to be tested are shown in black, the tester chromosomes in white, the inverted sections in the tester chromosomes by stippling.

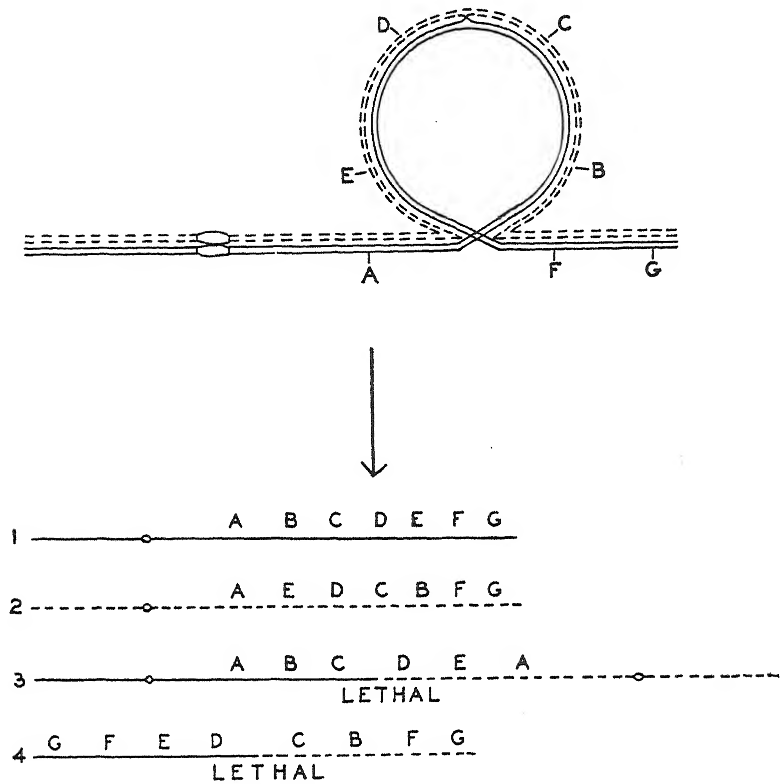

FIG. 2.—Diagram illustrating synapsis in an inversion heterozygote. The two chromatids represented by unbroken lines have the normal gene order A B C D E F G while in the two chromatids of the homologous chromosome, shown by broken lines, the order is A E D C B F G. The loop formed, when pairing occurs between all loci, includes those genes included in the inversion. A single crossover in the inverted region is shown between genes C and D. The products of this crossover are shown below. Chromatid 1 with the normal gene order and chromatid 2 with the inverted order are identical with the two parental chromosomes as far as loci within the inversion are concerned. They are viable because they have a full complement of genes. Chromatids 3 and 4 are both crossover strands and are non-viable since they have both duplications and deficiencies. Chromatid 3 had two spindle insertion regions while chromatid 4 has none. Since all crossovers, save certain types of rare multiples, within the inversion lead to non-viable chromosomes similar to 3 and 4 the group of genes within the inverted region are inherited en bloc.

others in duplicate. Such chromosomes are, as a rule, non-viable. If two crossovers occur within the inverted region and if the same two chromatids are involved at both points of crossing-over, chromosomes with a normal gene complement are obtained. They possess in the inverted region a block of genes derived from the homologous chromosome. Certain other types of double and multiple crossovers likewise produce viable chromosomes with a full gene complement but with blocks of genes obtained from homologous chromosomes. It is ap-

parent that the extent to which the presence of an inversion causes the genes in a chromosome to be inherited as a unit depends directly upon the frequency of certain types of crossovers. The information available in *Drosophila* shows that different inversions behave differently in this respect. One should note, however, that all inversions, except perhaps only the very short ones, decrease the frequency of crossing-over not only in the inverted segment, but likewise in the parts of the chromosome having identical gene orders but adjacent to the points of breakages.

Unfortunately, there is very little published information on the effects of inversions on crossing-over in maize. The cytological observations of McClintock (3) suggest, however, that at least some of the inversions in maize may behave similarly to some of those known in *Drosophila*. Although beyond doubt much remains to be done before suitable inversion-carrying strains can be developed in maize that would permit the localization of groups of desirable genetic factors, the task is by no means hopeless.

Inversions in maize are known to occur spontaneously, and they have been produced by X-ray irradiation. We may venture to outline the following scheme of work, subject to such modifications as experience will suggest. An inbred strain of maize carrying as many dominant mutant genes in as many different chromosomes as possible is to be treated with X-rays. The dominant genes will serve as chromosome markers. Evidently the genes must be so chosen as to be easily classifiable in hybrids with all or with most of the maize strains of commercial importance. The irradiation will produce inversions. Some of them will include those regions of different chromosomes marked by a dominant mutant gene. The extent of the inversions, as well as their effects on crossing-over, must subsequently be determined both genetically and cytologically.

Let us assume that an inversion in chromosome 1 including the dominant *P* gene is produced and that a stock homozygous for this inversion is obtained. This stock is then crossed with different inbred lines or with individual plants of a variety carrying the recessive *p* gene. Further procedure will depend upon whether an inbred line or an individual plant of a variety is to be used in the cross. Consider first the cross with an inbred line. The F_1 generation from the cross of the inversion strain by an inbred line will be uniform. On selfing a segregation into a 1:2:1 ratio is expected in F_2. One quarter of the F_2 plants, namely, those homozygous for *p*, carry in duplicate the chromosome 1 of the inbred line. The plants with the dominant *P* character are either homozygous or heterozygous for the inversion. These two classes usually can be distinguished because some aborted pollen is produced in most inversion heterozygotes (due to crossing-over, see above). Alternately, a backcross of the F_1 plants to the inbred parent results in a segregation of a 1:1 ratio. In either eventuality, the yield and other characteristics, such as lodging of the two classes of plants, are compared. The members of the two classes will occur at random within the progeny. Any statistically significant difference for any specific characteristic between the means of the two classes, which differ only by their chromosomes 1, is attributable to the effects of

genetic factors located in chromosome 1. If the frequency of the p p plants is significantly less than the expected value, the presence of a genetic factor, or factors affecting viability in chromosome 1 of the inbred line under test can be assumed.

The same inversion strain may be crossed with as many inbred lines as practicable and the yields of the recessive and dominant classes compared in all the crosses. If, for example, the recessive class yields 10 bushels per acre less than the dominant class when inbred A is used and only 5 bushels less when inbred B is involved, the data signify that inbred B carries a more favorable assemblage of genes in its chromosome 1 than inbred A does. When tests for many different lines are available it should be possible to identify that line, or those lines, which have the most desirable complement of genes in chromosome 1. If inversions were available covering all regions of the 10 chromosomes of maize, one could make a complete analysis of the genotype of any inbred line with regard to yield and other characters. Admittedly, this is a ponderous task, but one not beyond the range of possibilities in practice.

A somewhat different situation is met with when individual plants of an open-pollinated variety, rather than inbred lines, are to be tested. In a cross of the inversion strain by single individuals of a variety no two plants in the first generation are likely to have the same genetic constitution. It follows that the F_2 progeny from every F_1 plant must be tested separately. This means that a limited quantity of seed is available for testing. Whenever more seed is necessary the F_1 plants can be backcrossed to the inversion strain and the inversion homozygotes compared with the heterozygotes. In backcrosses with the inversion strain a test is made only for dominant genes located in chromosome 1 of the open-pollinated plant. If a recessive mutant gene rather than a dominant were included within the inversion, the recognition of the two classes would be facilitated. It is probable that the testing of the inbred lines would be more profitable and simpler, but both procedures may be required in a large breeding program.

Collections of lines known to carry desirable groups of genetic factors in definite chromosomes may be accumulated. These lines could be used as reservoirs of such factors. The problem of combining specific chromosomes from different strains into a single line presents certain technical difficulties that will not be discussed here. It will be a tedious task. We may point out, however, that even before this is done the method of localizing yield factors in definite chromosomes will be of service to the breeder. The ability to describe the genetic constitution of the inbred lines cannot but be helpful to him.

LITERATURE CITED

1. DOBZHANSKY, TH., and QUEAL, M. L. Genetics of natural populations. I. Chromosome variation in populations of *Drosophila pseudoobscura* inhabiting isolated mountain ranges. Genetics, 23:239–251. 1938.
2. ——————, ——————. Genetics of natural populations. II. Genic variation in populations of *Drosophila pseudoobscura* inhabiting isolated mountain ranges. Genetics, 23: (in press). 1938.

3. McClintock, Barbara, Cytological observations of deficiencies involving known genes, translocations and an inversion in *Zea mays*. Mo. Agr. Exp. Sta. Res. Bul. 163. 1931.
4. Richey, F. D., and Sprague, G. F. Experiments on hybrid vigor and convergent improvement in corn. U. S. D. A. Tech. Bul. 267. 1931.
5. Sturtevant, A. H. Autosomal lethals in wild populations of *Drosophila pseudoobscura*. Biol. Bul., 63:542–551. 1937.

ARTIFICIAL DROUGHT TESTS OF SOME HAY AND PASTURE GRASSES AND LEGUMES IN SOD AND SEEDLING STAGES OF GROWTH[1]

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DROUGHT resistance is important in hay and pasture grasses and legumes during all stages of growth. In the seedling stage resistance to drought may be of great importance in maintaining a stand after emergence. In many cases successful seedling stands of forages from early spring seeding have been killed in recent years in the early or late summer by severe hot and dry weather. Resistance to drought in later stages of growth may aid materially in maintaining established stands.

The studies reported here are a comparison of resistance under artificial trials in both the seedling and sod stages with behavior under field conditions.

LITERATURE REVIEW

Shirley (7, 8, 9)[3] has carried out numerous artificial drought tests on conifers. He studied seedlings from one to several years old and determined the length of treatment that produced death. The results of laboratory machine tests of drought resistance and of field survival during extremely dry periods are in good agreement. A description of the drought machine used and methods of handling plant material, together with results of tests, is given by Shirley and Meuli (9).

A machine was built in 1935 by Aamodt (1) for testing the resistance of wheat plants to drought. Atmospheric drought conditions were produced which were similar to those in the dry area of Alberta where young wheat plants often are injured severely. Wheat varieties which were known to be drought resistant under field conditions were less severely injured under artificial test than varieties known to be nondrought resistant.

Aamodt and Johnston (2) conducted an extensive test on spring wheat varieties. Three factors were considered to be of major importance in drought resistance, *viz.*, the ability to evade early periods of drought, capacity of developing root systems rapidly in the early stages of growth, and superior capacity to endure drought without permanent injury.

Bayles, Taylor, and Bartel (3) studied the drought resistance of eight wheat varieties comparing injury from the use of a hot-air blast over plants placed on a revolving table with the relative rates of water loss from cut plants. They found good agreement between various replicates in the artificial tests. Variety evaluations were consistent with field performance under drought conditions.

Artificial heat and drought tests were made on inbred strains of corn by Hunter, Laude, and Brunson (4). Susceptible firing lines under field conditions showed heavy injury due to treatment while the resistant lines showed little or no injury. Temperatures of approximately 140° F and a relative humidity of about 30% were used. The various tests gave consistent results and agreed well with field trials.

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[3]Figures in parenthesis refer to "Literature Cited", p. 681.

Peto (6) used a number of methods, including the drought chamber, in testing drought injury during early and late stages of plant growth. He found a diurnal effect which was caused especially by period variations in sunlight.

The Russian workers have studied drought resistance rather intensively. Aamodt and Johnston (2) and Peto (6) have reviewed the Russian literature which deals with crop plants, especially wheat.

In studies on the nature of drought resistance on a physico-chemical basis, Newton and Martin (5) arranged a number of grasses in order of drought resistance as indicated by their bound water percentages. Some of these species and percentages were crested wheat grass, 11.7; slender wheat grass, 10.3; brome grass, 10.3; Kentucky bluegrass, 5.3; and timothy, 4.5. Inter-annual correlation for bound water percentages gave an r value of 0.82 ± 0.06.

MATERIALS AND METHODS

The plant material used in this study was of three sorts—sod pieces, brought into the greenhouse about the middle of November and transplanted into pots, 60-day old seedlings, and 30-day old seedlings started in the greenhouse. All plants were grown in 4-inch clay pots containing a uniform soil mixture. The sod pieces were broken down to sizes of about 1 inch in diameter, while the 60-day seedlings were transplanted once from flats to pots and the 30-day seedlings were seeded directly into pots. There were varying numbers of plants per pot for these different forages, but it seemed that this was not a seriously disturbing factor in the testing.

Forage species and varieties that were under trial in the Minnesota Experiment Station pasture studies were used in this drought test. The sod group contained the following material: Commercial and pasture type timothy, forage and Fairway strains of crested wheat grass, commercial and non-creeping brome grass, Canada and Kentucky bluegrass, red and brown top, reed canary grass, meadow, creeping, and chewings fescue, meadow foxtail, slender wheat grass, orchard grass, Grimm alfalfa, and alsike clover. The two seedling groups contained the above material except slender wheat grass, reed canary grass, and brown top, and included, sweet, red, and white clover.

Through the courtesy of Dr. Shirley, the Lake States Forest Service drought machine was made available for the study of drought resistance of these forage grasses and legumes. This machine has a rotating platform upon which the plants are placed. Temperatures are raised by electric heating elements and also by electric bulbs which are used for lighting. Humidity is reduced rapidly by exhausting the heated atmosphere from the machine and also by the use of a calcium chloride dehydrating chamber. The wind velocity was held constantly at a rate of approximately 5 miles per hour.

Preliminary treatments of various durations were tried in order to find the treatment giving the best differential. The treatment conditions in the machine were similar for all trials, the only difference being in length of time of exposures. The pots were uniformly and heavily watered approximately one week before treatment and not again until immediately after removal from the machine. While the

soil was relatively moist upon entering the machine and seemingly dry at the end of the exposures, the drought was essentially an atmospheric one. Because of the elimination of water just previous to treatment, the plants may have hardened off to some extent.

Nine pots of each of the forage varieties in the sod group and in the 30-day old seedling group were grown. Eight pots were used for treatments and one as a check. For the 60-day old seedlings six pots were used for treatments and one as a check. All pots were randomized within growth stage groups and embedded into the soil in the bench for growing as an aid in obtaining uniform greenhouse environmental conditions.

For the 30-day old seedlings there were four replications of the 10-hour treatment and two each of the 16- and 20-hour treatments. The 60-day old seedlings had two replications for each of the 10-, 16-, and 20-hour treatments, while for the sod plants two replications were used for the 16- and 20-hour treatments and four for the 26-hour treatment.

A record of temperature and percentage of relative humidity was made every few hours during the various trials. The ultimate temperature of each test was about 43° C, with a relative humidity of about 17%. After treatment, the plants were again placed on the greenhouse bench in position with their checks for two weeks before readings were made of drought injury.

The seedling pot or unit represented a relatively large number of young individuals, while the sod was a mass of plant material of a definite size rather than a number of plants or tillers. The same injury reading scale therefore did not lend itself well for comparable readings. The following scale was used for the seedlings:

0—All plants completely killed.
1—From 1 to 5% of plants showing some life.
2—From 6 to 20% of plants showing some life.
3—From 21 to 33% of plants showing some life.
4—From 34 to 50% of plants showing some life.
5—From 51 to 66% of plants showing some life.
6—From 67 to 80% of plants showing some life.
7—From 81 to 100% of plants showing some life.
8—All plants alive with leaves injured severely.
9—All plants alive with tips of leaves dead.
10—No injury; comparable to check.

The scale used for the sod material was made with the following seven classes.

0—All plant material dead.
1—Very slight recovery.
2—Weak recovery.
3—Fair recovery.
4—Medium recovery.
5—Good recovery.
6—No injury; equal to check.

EXPERIMENTAL RESULTS

The results of different replications were in general very consistent. The readings of duplicate or quadruplicate pots of like treatment varied in only a few cases more than two and three points on the seedling reading scale, while most of the readings were practically identical. Readings on the sod material were even more uniform with no greater discrepancy than two points. The mean readings of drought injury for the three types of growth stages are given in Table 1.

TABLE 1.—*Mean comparative injury of 30-day seedlings, 60-day seedlings, and sod plants in readings of 0–10 scale for seedlings and 0–6 for sods, after drought treatment of 10, 16, 20 and 26 hours duration. (0 = complete death in each growth stage group).*

Pot No.	Forage crop	Treatment in hours for growth stage groups*								
		30-day seedlings			60-day seedlings			Sod material		
		10†	16	20	10	16	20	16	20	26†
1	Timothy, commercial	3.8	0.0	0.0	8.5	7.5	0.0	4.0	3.5	1.7
2	Crested wheat grass, forage	9.0	9.0	2.5	9.0	7.0	5.5	5.5	4.0	2.5
3	Timothy, pasture type	2.8	0.0	0.0	7.5	6.5	0.0	4.0	2.0	0.5
4	Brome grass, commercial	9.0	7.0	4.0	9.0	8.0	8.0	6.0	5.0	3.8
6	Crested wheat grass, Fairway	8.0	7.0	0.0	7.0	6.0	2.0	6.0	3.0	0.8
7	Brome grass, non-creeping	8.5	4.0	0.0	9.0	9.0	4.0	5.5	4.0	3.0
9	Reed canary grass	—	—	—	—	—	—	4.0	3.0	1.0
10	Meadow fescue	8.0	4.0	0.5	9.0	8.0	4.5	3.5	1.0	0.0
11	Canada bluegrass	3.8	0.0	0.0	8.5	6.5	1.5	5.5	3.0	1.0
13	Meadow foxtail	3.8	1.5	0.0	8.5	7.0	4.5	4.5	3.0	1.0
14	Kentucky bluegrass	3.2	0.0	0.0	8.0	7.0	1.0	5.0	2.5	1.0
15	Slender wheat grass	—	—	—	—	—	—	5.0	5.5	3.0
17	Chewings fescue	6.2	1.5	0.0	8.0	6.0	0.5	5.5	1.5	0.2
19	Creeping fescue	7.2	3.5	0.0	9.0	9.0	0.5	4.5	2.5	0.2
21	Brown top	—	—	—	—	—	—	2.0	0.5	1.2
22	Orchard grass, commercial	5.5	1.5	0.0	8.5	6.0	1.0	5.0	2.5	1.5
23	Red top	2.2	0.0	0.0	8.0	4.0	0.5	3.0	0.0	0.2
36	Alsike clover	4.2	0.5	0.0	7.0	4.0	0.0	5.5	2.0	0.5
41	Alfalfa, Grimm	8.5	3.5	0.0	9.0	7.5	4.0	5.0	4.5	1.2
46	Wh. Bl. sweet clover	8.0	0.0	0.0	8.5	4.0	0.0	—	—	—
51	Medium red clover	2.0	0.0	0.0	6.0	2.0	0.0	—	—	—
62	White clover	1.8	0.0	0.0	6.0	2.0	0.0	—	—	—

*0 = Complete death in each growth stage group.
†Average of 4 replications, whereas the other treatment periods are averages of 2 replications.

For the 30-day old seedlings the 20-hour drought exposure was lethal to all varieties of grasses and legumes tested except forage crested wheat grass, commercial brome grass, and meadow fescue. One of the two pots of meadow fescue received a score of 1 by having some survival. The brome grass had about a one-third to one-half survival, while the crested wheat grass showed about 25% survival.

The 16-hour treatment for this growth stage gave much less severe injury. Forage crested wheat grass with a scale reading of 9 had tip injury of the leaves. Commercial brome grass and the Fairway strain of crested wheat grass showed severe foliage injury and a small per-

centage of seedlings that were killed. Non-creeping brome grass, meadow fescue, creeping fescue, and Grimm alfalfa all survived 20 to 50%. Other forages were very severely injured or entirely killed.

The 10-hour treatment gave less injury than longer treatments and all forages had some survival. Commercial and pasture type timothy, Canada and Kentucky bluegrass, meadow foxtail, red top, and medium red and white clover were injured most severely. The two strains of timothy and the two strains of brome grass in this growth group are shown in Fig. 1 after 10 hours and 16 hours treatments together with their checks.

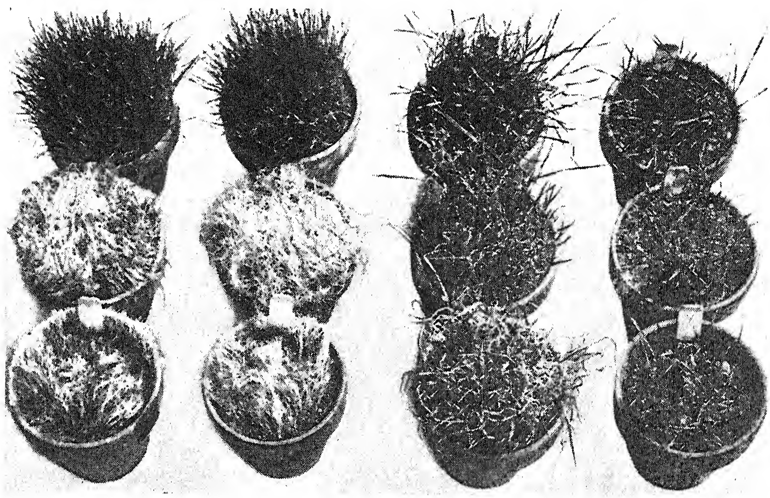

FIG. 1—Comparative injury by artificial drought on two strains of timothy and two strains of brome grass in 30-day-old seedlings. The three-pot rows from left to right are commercial timothy, pasture type timothy, commercial brome grass, and non-creeping brome grass. The front row of pots was exposed to drought for 16 hours, the second row for 10 hours, and the back row are the untreated checks. The photo was taken two weeks after the drought treatment.

The comparative injury to the 60-day growth stage group was similar to that of the 30-day-old seedlings except that injury was less severe. For the 20-hour exposure, commercial and non-creeping brome grass, forage crested wheat grass, meadow fescue, meadow foxtail, and Grimm alfalfa had 50% or better of survival. Meadow foxtail was much more drought resistant in the 60-day seedling stage than in the 30-day seedling stage. With 16 hours of exposure all forages withstood the drought test relatively well, except for white and red clover which showed only about 20% survival. The 10-hour exposure was much less injurious than the longer exposures, with red and white clover showing most severe injury.

More severe treatments were necessary for a good differential in the sod materials. Slowness of recovery from injury rather than complete death was usually common in this group. The averages for the 26-

hour exposure in Table 1 comprise a mean of four replications. The hardier types of grasses were forage crested wheat grass, commercial and non-creeping brome grass, and slender wheat grass. Other forages with somewhat less than fair recovery according to the scale used were commercial timothy, Fairway crested wheat grass, reed canary grass, Canada and Kentucky bluegrass, meadow foxtail, brown top, orchard grass, and Grimm alfalfa.

While it is not possible to compare directly the sod growth stage readings and those of the seedlings, there is rather consistent agreement between all three stages. In comparing the two seedling groups it is noticeable that with comparable treatments the older seedlings possessed considerably more resistance to these drought conditions than did the 30-day-old plants.

During the last two years these same forages have been grown in single plots without replication at the central station in St. Paul and at the branch stations at Waseca, Morris, Grand Rapids, and Duluth. One end of each plot was cut with a lawn mower whenever the plants reached approximately 4 inches in height and the other end of the plot was harvested at the proper hay stage. A further year's study of these plots will be made before the data are studied in detail and survival determined in relation to botanical composition.

Drought conditions were most severe at University Farm and Morris. Stands of brome grass and crested wheat grass were successful when other forages were injured by drought. Alfalfa, while not as resistant as these two grasses, resisted drought better than sweet clover. Other clovers were killed completely. Varieties of grasses or legumes that best withstood drought injury under field conditions were most resistant also when tested under artificial drought conditions either in the 30- or 60-day-old seedling stages or in the sod stage of growth.

SUMMARY

A series of forage grasses and legumes, which have been grown under field trials at the central and branch stations in Minnesota in the past two years, were tested for drought resistance in an artificial drought machine. There was very good agreement of results of these artificial drought trials with those obtained under field conditions. In both tests, crested wheat grass and brome grass proved most drought resistant, while among the legumes, alfalfa was most drought resistant. Artificial tests of drought resistance may be used therefore to indicate those species or varieties of forages which can be expected to succeed best under natural drought conditions.

LITERATURE CITED

1. AAMODT, O. S. A machine for testing the resistance of plants to injury by atmospheric drought. Can. Jour. Res., 12:788–795. 1935.
2. ————, and JOHNSTON, W. H. Studies on drought resistance in spring wheat. Can. Jour. Res., 14:122–152. 1936.
3. BAYLES, B. B., TAYLOR, J. W., and BARTEL, A. T. Rate of water loss in wheat varieties and resistance to artificial drought. Jour. Amer. Soc. Agron., 29: 40–52. 1937.

4. HUNTER, J. W., LAUDE, H. H., and BRUNSON, A. M. A method for studying resistance to drought injury in inbred lines of maize. Jour. Amer. Soc. Agron., 28:694–698. 1936.
5. NEWTON, R., and MARTIN, W. M. Physico-chemical studies on the nature of drought resistance in crop plants. Can. Jour. Res., 3:336–427. 1930.
6. PETO, HOWARD B. A method of studying drought resistance in plants. Master's thesis, Univ. of Alberta, Canada. 1937.
7. SHIRLEY, H. L. A method for studying drought resistance in plants. Science, 79:14–16. 1934.
8. ————. Lethal high temperatures for conifers and cooling effect of transpiration. Jour. Agr. Res., 53:239–258. 1936.
9. ————, and MEULI, L. J. The influence of moisture supply on the drought resistance of conifers. Jour. Agr. Res. (In press.) 1938.

EFFECT OF FERTILIZATION, CUTTING TREATMENTS, AND IRRIGATION ON YIELD OF FORAGE AND CHEMICAL COMPOSITION OF THE RHIZOMES OF KENTUCKY BLUEGRASS (*Poa pratensis* L.)[1]

H. L. Ahlgren[2]

It has long been known that the pasture complex is the resultant of the interplay of climatic, soil, and biotic factors; the latter including pasture management. Numerous investigations made under varying soil and climatic conditions have provided considerable information relative to the improvement of grassland by the use of commercial fertilizers. In general, the data which have been accumulated indicate that marked responses may be obtained by the use of commercial fertilizers on soils which are deficient in fertility (1, 2, 3, 4, 5, 6, 12, 15).[3]

Most studies relative to the management of pasture grasses and legumes which have been described in the literature were designed to compare yields of forage obtained under a system of frequent defoliations with that of a hay stage of growth. Conclusive evidence is available to indicate that forage cut or grazed closely and frequently is injured and yields are reduced (7, 8, 9, 10, 11, 13, 14, 16, 18). It has also been shown that different species react differently to different intensities of grazing. Graber, *et al.* (10), found that where 22 close cuttings with a lawn mower did not kill Kentucky bluegrass, only 9 cuttings of alfalfa resulted in death to nearly all plants. Carrier and Oakley (5) and Wiggans (17) have reported that Kentucky bluegrass yields approximately as much when cut frequently as when cut for hay.

The objectives of the study reported in this paper were (a) to determine the effect of different intensities of clipping on the yield of Kentucky bluegrass, (b) to study the response of Kentucky bluegrass to complete fertilization and irrigation, and (c) to determine the effect of the different clipping and fertilization treatments on the carbohydrate reserve of the rhizomes.

PLAN OF EXPERIMENT

The experiment reported herein was begun in 1931 and concluded in the fall of 1936. It was located on the West Hill University Farm at Madison, Wisconsin, on an old bluegrass sod. The soil on which the studies were made is a Miami silt loam varying in pH from 5.8 to 6.3. The plats were 1/200 acre in size each separated by a 2-foot alley. All of the fertilizer and cutting treatments were replicated four times.

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[3]Figures in parenthesis refer to "Literature Cited", p. 690.

Three different cutting variables were employed in the experiment. The first cutting variable was intended to approximate normal controlled grazing. The grass was permitted to grow to a 4- to 5-inch height and then cut, leaving a stubble of 1½ inches. The second type of cutting management was designed to imitate the effect produced under a system where grazing is deferred in the spring. The grass was cut in the early heading stage, just as the panicles were emerging from the sheaths, leaving a stubble of 1½ inches. The aftermath produced thereafter was removed whenever it reached a height of 4 to 5 inches. The third cutting variable was included to study the comparative effect of permitting the grass to make an uninterrupted growth to a late heading stage before harvesting. The hay was cut down to a 1½-inch level and the aftermath removed regularly when 4 to 5 inches high.

One-half of the plats in each cutting series were fertilized at the acre rate of 200 pounds of muriate of potash, 400 pounds of 20% superphosphate, and 400 pounds of ammonium sulfate. The remaining plats were not fertilized. The nitrogen fertilizer was applied each year in a single application in the early spring. The mineral fertilizers were applied only in 1932. Cutting was done with a lawn mower equipped with a grass catcher except on the plats permitted to grow to a late hay stage where a scythe was used. Preliminary cutting studies on the area in 1931 prior to the time the fertilizers were applied indicated a marked uniformity in yield from all plats.

Because of unusual early season drought conditions prevailing in 1934, one series of the replicated plats was removed from the regular experiment and irrigated at the rate of 1½ inches of rainfall per week. The purpose of this study was to compare the yield of forage obtained under favorable and unfavorable moisture conditions. The yield of forage produced by each of the irrigated plats was calculated.

Beginning on June 27 and at 3-week intervals thereafter, representative duplicate sods were removed from each of the irrigated plats. The sod samples were removed a week after a cutting was made. The sods thus obtained were washed free of soil and the rhizomes collected. The rhizomes removed from each sod were placed in paper bags and dried at room temperature until early winter, when they were oven dried at 80° C, ground to pass an 80-mesh sieve, and analyzed for carbohydrate content. The method used for analyzing the rhizomes is that described in the third edition of the Official and Tentative Methods of Analysis of the Association of Agricultural Chemists.

RESULTS

EFFECT OF DIFFERENT INTENSITIES OF CLIPPING ON YIELD OF KENTUCKY BLUEGRASS

The detailed data with respect to yield as affected by the cutting treatments used is given in Tables 1 to 4, inclusive. Fisher's analysis of variance was used in evaluating the significance of the differences in yield which were obtained. The minimum difference required for significance at the 5% point between cutting treatments for each fertilizer level was found to be 474.8 pounds per acre. When this value is used as a test of significance, the yield of forage produced in 1932 by the fertilized plats cut as the heads were appearing was significantly higher than that obtained from either the plats cut when 4 to 5 inches high or when fully headed. The yield of forage produced by the fer-

tilized plats cut when 4 to 5 inches high was significantly lower than that obtained from the plats cut as heads were appearing or when fully headed. Differences were not great enough to be of any significance on the unfertilized plats, but the trend was in the same direction. In 1933 the unfertilized plats which were not cut until fully headed were significantly higher in productivity than those cut when 4 to 5 inches high or as heads were appearing. There were no other significant differences in yield due to cutting treatment in 1933, 1934, 1935, or 1936.

TABLE 1.—*The effect of various cutting treatments and fertilization on the yield of Kentucky bluegrass when given complete fertilization.**

Year	Calculated acre yield of dry matter (pounds) at various stages of growth					
	4–5 inches		Early heading		Fully headed to mature	
	Not fertilized	Fertilized	Not fertilized	Fertilized	Not fertilized	Fertilized
1932	1,619	3,113	2,081	4,769	2,050	3,957
1933	2,153	4,295	2,341	4,439	2,977	4,579
1934	1,817	2,114	1,742	2,319	1,681	2,046
1935	1,520	1,932	1,418	1,932	1,279	1,785
1936	826	1,703	595	1,617	435	1,617
Average	1,587	2,631	1,635	3,015	1,684	2,797

*Minimum significant difference in pounds of dry matter between means at 5% level:
Years—193.8.
Fertilizers—122.6.
Years × Cuttings × Fertilizers—474.8.

TABLE 2.—*Analysis of variance of data presented in Table 1.*

Item	D.F.	Variance	F value	5%	1%
Years	4–	16378432.57	193.77	2.56	3.72
Cutting treatment	2–	355564.98	4.21	3.18	5.06
Fertilizers	1–	31256491.21	369.79	4.03	7.17
Years × cutting treatments	8–	507228.69	6.00	2.13	2.88
Years × fertilizer treatments	4–	2721138.41	32.19	2.56	3.72
Years × replicates	10–	123805.62	1.46	2.02	2.70
Cutting treatments × fertilizer treatments	2–	241075.20	2.85	3.18	5.06
Years × cutting treatments × fertilizer treatments	8–	129330.32	1.53	2.13	2.88
Error	52	—	—	—	—
Total	91	—	—	—	—

That there was a definite trend in productivity favoring the 4- to 5-inch cutting level on both the fertilized and unfertilized series, even though not significant in any given year, is evident from a review of the data given in Table 4. If the annual productivity of the plats cut when fully headed is taken as 100, the relative yield of forage produced by the fertilized plats cut when 4 to 5 inches high was 79, 92, 113, 108.2, and 143.6 during the period 1932 to 1936, respectively. Likewise, the relative yield of forage produced by the unfertilized plats cut

TABLE 3.—*The effect of various cutting treatments on the yield of irrigated Kentucky bluegrass, 1934.*

Calculated acre yield of dry matter (pounds) at various stages of growth					
Complete fertilization			No fertilization		
4–5 inches	Early heading	Fully headed to mature	4–5 inches	Early heading	Fully headed to mature
5,231	4,631	4,719	2,795	2,438	2,292

TABLE 4.—*Percentage yield of Kentucky bluegrass from various cutting and fertilization treatments for 1932–36, inclusive, when compared to the plats cut at maturity and using 100 as an index of their yield.*

Year	Complete fertilization			No fertilization		
	4–5 inches	Early heading	Fully headed to mature	4–5 inches	Early heading	Fully headed to mature
1932	79	123	100	71	93	100
1933	92	97	100	74	81	100
1934	113	103	100	108	101	100
1934*	111	98	100	122	106	100
1935	108.2	108.2	100	118.8	110.8	100
1936	143.6	105.4	100	189.8	136.7	100

*Irrigated.

when 4 to 5 inches high was 71, 74, 108, 118.8, and 189.8 during the period 1932 to 1936, respectively. The same general trend found in the series cut when 4 to 5 inches high is evident on both the fertilized and unfertilized plats cut as heads were appearing although it is not as pronounced.

While these transition differences have not been great enough to show significance in any one year, they do indicate a definite trend in the direction favoring the 4- to 5-inch cutting procedure. It is believed that the relative decreased productivity of the plats on which cutting was deferred until the bluegrass was fully headed may have been due in part to the natural thinning of the turf which resulted from this type of management and the noticeably slower growth recovery from cutting.

RESPONSE OF KENTUCKY BLUEGRASS TO FERTILIZATION AND IRRIGATION

The data given in Tables 1 and 2 indicate that increases in productivity due to fertilization were highly significant in all cases in spite of the unusual drought conditions which prevailed during four of the five years the experiment was in progress. The application of complete fertilization to unirrigated plats increased the average acre yield of dry matter during the 5-year period 1,113 pounds, or 66.1%, on the plats cut when the bluegrass was fully headed; 1,380 pounds, or 84.4% on those cut when seed heads were just appearing; and 1,044 pounds, or 65.8%, on plats cut periodically when 4 to 5 inches high.

The average annual acre increase in yield due to fertilization for all cutting treatments was 1,179 pounds, or 72.1%.

That lack of sufficient moisture may effectively reduce the productivity of Kentucky bluegrass is evident from the data given in Tables 1 and 3. During 1934, one series of the cutting treatments was irrigated in order to eliminate moisture as a limiting factor of growth. Under irrigation, complete fertilization increased the acre yield of dry matter 2,427 pounds, or 105.8%, on the plats cut when the bluegrass was fully headed; 2,193 pounds, or 89.9%, on those cut when the seed heads were just appearing; and 2,436 pounds, or 86.8%, on plats cut when the grass was 4 to 5 inches high. The average increase in yield due to fertilization on the irrigated plats for all cutting treatments was 2,352 pounds, or 94.2%.

The average calculated acre increase in yield of dry matter as a result of irrigation on all of the fertilized plats regardless of cutting treatment was 2,700 pounds, whereas the increase as a result of irrigation on corresponding unfertilized plats was 761 pounds. Irrigation increased the average yield 125% on the fertilized plats and 43.6% on the unfertilized plats. A lower increase in yield due to irrigation was obtained from the unfertilized plats than from those which had been fertilized because the fertility necessary for maximum growth was lacking. The data indicate conclusively that moisture and fertilization were both highly significant in increasing production for all of the cutting treatments.

The data given in this paper show that with the exception of 1933, there was a progressive and significant decrease in the yield of bluegrass on all plats, regardless of the cutting or fertilizer treatment used, during the period 1932 to 1936, inclusive. There is no indication in the data that the fertilizer or cutting treatments used affected the rate of decrease. The average acre yield of dry matter produced by all of the fertilized plats decreased from 3,947 pounds in 1932 to 1,647 pounds in 1936. During the same period, the average acre yield of dry matter produced by the unfertilized plats decreased from 1,917 to 619 pounds. No reason can be cited to account for these decreases. Unfavorable seasonal conditions may have resulted in thinning of the turf thereby decreasing the yield. The grazing animal is known to have a beneficial effect on the sward, although the exact nature of the benefit derived is not fully understood.

Since much of the information available relative to the improvement of permanent pastures has been based on results obtained from the "lawn mower" type of experiment, it would appear highly desirable to run correlation studies on yield obtained under grazing and clipping treatments.

EFFECT OF DIFFERENT CLIPPING AND FERTILIZER TREATMENTS ON CARBOHYDRATE RESERVE OF THE RHIZOMES

During 1934 representative duplicate square foot sods were removed at 3-week intervals from each of the variously fertilized and clipped irrigated plats. The sods were washed free of soil and the rhizomes removed. Sampling was begun June 27. The rhizomes which

were collected from the variously treated plats were analyzed for their carbohydrate content. The results of this analysis are given in Table 5 and in Figs. 1 and 2. From a review of the data it is evident that the carbohydrate content of the rhizomes of Kentucky bluegrass was higher on the unfertilized plats than on the fertilized plats regardless of the cutting treatment used. This is to be expected since the more rapid growth which results from the use of commercial fertilizers, especially nitrogen, does not lead to an accumulation of large supplies of organic reserves in rhizomes.

TABLE 5.—*Percentage starch equivalent in the rhizomes of Kentucky bluegrass when cut at different stages of growth, 1934.*

Date	Complete fertilization			No fertilization		
	4–5 inches	Early heading	Fully headed to mature	4–5 inches	Early heading	Fully headed to mature
June 27	11.45	17.78	17.35	16.56	18.00	18.65
July 17	16.56	14.00	13.21	18.32	14.05	14.00
Aug. 8	16.70	15.12	13.21	21.24	15.44	14.00
Aug. 27	19.62	19.15	17.78	26.03	21.60	20.45
Oct. 19	23.72	21.10	20.20	26.86	22.07	21.92
Nov. 8	27.04	27.04	27.04	27.18	29.02	28.19

The carbohydrate content of the rhizomes of Kentucky bluegrass cut when 4 to 5 inches high increased progressively from the first date of sampling to the end of the growing period. Apparently a system of management which permits of a return growth of 4 to 5 inches does not lead to a depletion of organic reserves.

Deferring cutting until the early or late heading stages increased the carbohydrate content of the rhizomes at both fertility levels. However, there was a significant decrease in the carbohydrate reserve of the rhizomes under the deferred cutting conditions immediately after the first cutting. Fewer green leaves remained after cutting than on the areas cut regularly when 4 to 5 inches high because of the shading and crowding effect which obviously results from a system of management of this type. Consequently, after the taller top growth was removed, new growth was initiated more completely at the expense of previously stored reserves. With the return of an adequate leaf surface the carbohydrate content increased progressively during the remainder of the growing period.

The data would appear to indicate that none of the systems of management used under the conditions of this experiment would lead to a depletion of organic reserves.

SUMMARY

Results of a field study with Kentucky bluegrass conducted at Madison, Wis., during the period 1932 to 1936, inclusive, are presented. The purpose of the study was to determine (a) the effect of different intensities of clipping on the yield, (b) the response to fer-

tilization and irrigation, and (c) the effect of different cutting and fertilizer treatments on the carbohydrate content of the rhizomes. The data were analyzed according to Fisher's analysis of variance.

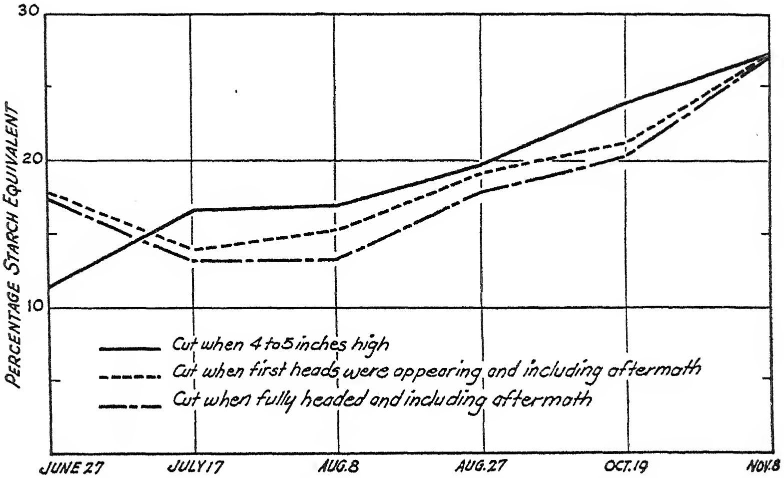

FIG. 1.—Percentage starch equivalent in the rhizomes of Kentucky bluegrass when cut at different stages of growth and receiving complete fertilization.

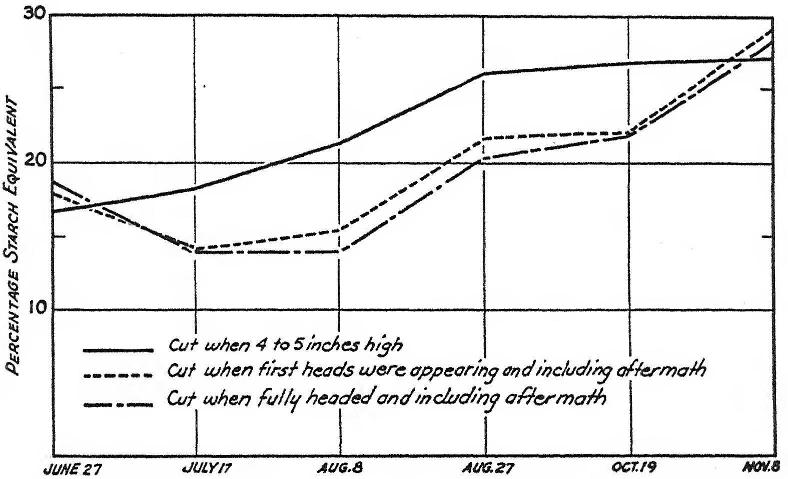

FIG. 2.—Percentage starch equivalent in the rhizomes of Kentucky bluegrass when cut at different stages of growth and not fertilized.

Differences in yield resulting from three cutting variables used were not significant except during the first year of the experiment. However, as the experiment progressed, there was a definite trend in productivity favoring the 4- to 5-inch cutting level on both the fer-

tilized and unfertilized plats even though yearly differences were not significant.

The application of phosphate and potash in 1932 and nitrogen annually, increased the average yield of dry matter 1,179 pounds, or 72.1%, during the 5-year period on the plats which were not irrigated. In 1934 the fertilized plats which were irrigated produced 94.1% more forage than the irrigated unfertilized plats.

During 1934 the fertilized plats which were irrigated at weekly intervals produced 125% more forage than the fertilized plats which were not irrigated. The irrigated plats which were not fertilized produced 43.6% more forage than the unfertilized plats which were not irrigated.

Under the conditions of this experiment, moisture, fertilization, and cutting treatments were effective in the order given in determining the productivity of Kentucky bluegrass. There were no significant interactions between fertilizer and cutting treatments.

There was a significant and progressive decrease in yield for all fertilizer and cutting treatments due to cutting during the period 1932 to 1936, inclusive.

The carbohydrate content of the rhizomes was not appreciably reduced by any of the fertilizer or cutting treatments used on the irrigated plats during 1934.

LITERATURE CITED

1. BARNES, E. E. Effect on permanent pastures of treatment with limestone and acid phosphate as measured by the quantity and quality of vegetation produced. Jour. Amer. Soc. Agron., 16:241–251. 1924.
2. BROWN, B. A. Report of the Director for the year 1930. Conn. (Storrs) Agr. Exp. Sta. Bul. 171. 1931.
3. ————. Effects of fertilizers on the seasonal production of pastures. Jour. Amer. Soc. Agron., 24:898–908. 1932.
4. ————, and SLATE, W. L. The maintenance and improvement of permanent pastures. Conn. (Storrs) Agr. Exp. Sta. Bul. 155. 1929.
5. CARRIER, L., and OAKLEY, R. A. The management of bluegrass pastures. Va. Agr. Exp. Sta. Bul. 204. 1914.
6. DAVIES, W., and JONES, E. The yield and response to manures of contrasting pasture types. Welsh Jour. Agr., 8:170–192. 1932.
7. GRABER, L. F. Unpublished data. Wis. Agr. Exp. Sta. 1930.
8. ————. Penalties of low food reserves in pasture grasses. Jour. Amer. Soc. Agron., 27:29–33. 1929.
9. ————. Competitive efficiency and productivity of bluegrass with partial defoliations at two levels of cutting. Jour. Amer. Soc. Agron., 25:328–333. 1933.
10. ————, NELSON, N. T., LEUKEL, W. A., and ALBERT, W. B. Organic food reserves in relation to the growth of alfalfa and other herbaceous plants. Wis. Agr. Exp. Sta. Res. Bul. 80. 1927.
11. HARRISON, C. M. Responses of Kentucky bluegrass to variations in temperature, light, cutting and fertility. Plant Phys., 9:83–106. 1934.
12. HUTCHESON, T. B., and WOLFE, T. K. The fertilization and management of bluegrass pastures. Va. Agr. Exp. Sta. Ann. Rpt. 1919.
13. LEUKEL, W. A., and COLEMAN, J. M. Growth behavior and maintenance of organic foods in Bahia grass. Fla. Agr. Exp. Sta. Tech. Bul. 219. 1930.
14. MORTIMER, G. B., and AHLGREN, H. L. Influence of fertilization, irrigation, and stage and height of cutting on yield and chemical composition of Kentucky bluegrass. Jour. Amer. Soc. Agron., 28:515–533. 1936.
15. PARSONS, C. B. An intensive system of grassland management. Mass. Agr. Exp. Sta. Bul. 9. 1928.

16. PIERRE, W. H., and BERTRAM, F. S. Kudzu production with special reference to influence of frequency of cutting on yield and formation of root reserves. Jour. Amer. Soc. Agron., **21**:1079–1101. 1929.
17. WIGGANS, R. G. Studies of various factors influencing the yield and duration of meadow and pasture plants. Cornell Univ. Agr. Exp. Sta. Bul. 424. 1923.
18. WOLFE, T. K. The yield of various pasture plants at different periods when harvested as pasturage and as hay. Jour. Amer. Soc. Agron., 18:381–384. 1926.

A COMPARISON OF MITSCHERLICH TRIALS ON HAWAIIAN SOILS IN GERMANY AND IN THE TERRITORY OF HAWAII[1]

O. C. MAGISTAD[2]

THE use of the Mitscherlich pot culture method (4)[3] for detecting soil deficiencies has become commonplace throughout parts of Europe. Its use outside of Europe has been little investigated. With a view towards possible use of this method for diagnosing pineapple soils in the territory of Hawaii, soil samples were obtained in 1930 from seven field experiments. Mitscherlich pot culture tests were conducted on these soils in Germany, and later in Hawaii, and this paper reports and compares the results obtained.

EXPERIMENTAL PROCEDURE

PREPARATION AND DESCRIPTION OF SOILS

The soils used were collected by taking a uniform section to the depth of about 12 inches at regular, frequent intervals throughout the experimental area. The entire sample of about 500 pounds from a single field was thoroughly mixed for several hours in a large clean cement mixer. Approximately one-half was shipped in barrels to E. A. Mitscherlich in Konigsberg, East Prussia, Germany. The remainder was stored in Honolulu for later tests.

The seven soils used are described in Table 1 together with some of their characteristics.

The percentage of colloids as shown in Table 1 was determined using the method of Bouyoucos (2) with temperature corrections as indicated by Richter (6).

TABLE 1.—*Description of soils used.*

Soil No.	Experiment No.	Island	Colloid %	pH	Readily available	
					P, p.p.m.	K_2O, M.E./100 grams
39A	K. P. 9	Kauai	62.3	7.0	20	0.65
85	H. P. report 7	Oahu	N.D.	6.0	12	1.15
L4	H. P. 13	Lanai	N.D.	6.6	14	1.31
1	Libby 98-G	Molokai	74.9	6.5	13	0.95
71	Libby 98-D	Oahu	72.7	4.8	12	0.92
109	Libby 98-C	Oahu	N.D.	4.8	N.D.	0.47
KP5	K. P. 5	Kauai	74.6	4.8	16	0.47

The method of Bouyoucos includes some of the finer silt with the colloidal fraction, tending to make results too high. On the other hand, dispersion may not have been complete although the soil was stirred by an electric stirrer for 1 hour. The values as recorded show that the soils were highly colloidal, but all of them

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[3]Figures in parenthesis refer to "Literature Cited", p. 698.

have a mealy to fine crumb structure. The soils contain about 2% organic matter, are lateritic, contain in general less than 25% silica, and have a high fixing capacity for phosphorus.

Soil reaction was determined as recommended by de' Sigmund (3) in a 1:2 soil water suspension using the hydrogen electrode. Readily available phosphorus was determined as described by Truog (7), and potash by the method of Volk and Troug (8).

GREENHOUSE PROCEDURE

In Germany the greenhouse trials were conducted under the direction of Professor Mitscherlich following the method indicated in his publication (4) with the exception that the amount of the three plant foods, N, P_2O_5, and K_2O, added per pot varied in steps as follows: 0, 0.1, 0.25, 0.6, and 1.5 grams per pot. Each of the above plant foods was varied singly while the other two principal elements remained constant at 1.5 grams per pot. There were three pots to a treatment except in the case of complete fertilization where there were four replications. The crop grown was Lochows Petkuser Gelbhafer oats. Seeding occurred on May 6, 1931, and harvesting on August 17 and 19, 1931.

In Hawaii the author attempted to duplicate the greenhouse procedure of Professor Mitscherlich as closely as possible. Lochows Petkuser oats was obtained from Professor Mitscherlich and was used as the indicator crop. The plants were kept outside until heading occurred, except during periods of rain. Wind storms caused some lodging in the treatments receiving high nitrogen. The dates of seeding and harvesting varied with the soil used and will be discussed later. These Hawaii tests were conducted in the fall of 1932 and the spring of 1933.

RESULTS

The mean grain plus straw weights are recorded in Table 2 in percentage of the maximum yield. The maximum yield in grams, together with the mean standard error in grams, is also given so that the actual mean yield of a treatment, together with its standard error can be computed. In computing the standard error for a treatment the following formula was used: $\sigma = \sqrt{\frac{d^2}{n(n-1)}}$, where d = difference of a pot yield from the mean. The value 6 was used in the denominator where there were three pots receiving the same treatment. The mean standard errors as reported in Table 2 are means for a particular soil of the standard errors of individual treatment in grams.

DISCUSSION

Probably the most striking difference between trials in Germany and in Hawaii is that of lengths of time required for maturity. In Germany the oats were ripe 73 days after seeding, while in Hawaii this period ranged from 82 days to 172 days, depending on the date of planting. It is presumed that maturity is retarded in Hawaii at 21° North latitude because days are relatively short even in summer compared to length of days in summer at Konigsberg at a latitude of 55° North. The evidence in Table 3 also confirms this for oats grown during the longer days of May to July matured in 82 days, while oats grown during the winter required 149 to 172 days.

TABLE 2.—*Yields of oats on seven Hawaiian soils in Mitscherlich pot tests conducted in Germany and in the Territory of Hawaii.**

Grams plant nutrient added per pot	Field 39		Field 85		Field L4		Field 1		Field 71		Field 109		Field K.P. 5	
	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii
					Nitrogen Variable									
0.0	5.8	9.4	7.5	18.1	17.7	22.3	6.6	13.8	5.1	16.1	5.3	10.1	8.6	19.6
0.1	9.5	18.3	14.5	26.8	27.2	32.6	11.5	20.4	8.9	23.6	11.6	22.7	13.8	30.0
0.25	21.6	32.5	26.0	39.7	37.3	42.3	19.0	36.5	19.5	34.5	23.9	44.1	27.4	42.5
0.6	45.8	48.8	57.9	53.9	56.5	62.7	47.2	51.6	47.9	52.6	52.7	73.1	59.8	68.0
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
					Phosphorus Variable									
0.0	26.6	61.4	7.7	9.7	10.1	32.6	5.7	32.6	6.2	38.6	7.8	62.2	9.9	9.2
0.1	50.6	70.3	19.1	22.3	25.3	62.8	16.2	49.6	13.9	55.4	20.1	71.5	16.3	18.1
0.25	71.2	84.8	37.7	59.3	47.7	87.0	42.1	71.6	31.1	81.1	48.2	88.3	26.3	37.6
0.6	98.7	86.1	82.3	79.8	88.4	100.0	86.1	86.5	89.8	79.6	87.7	92.4	46.3	39.0
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
					Potash Variable									
0.0	87.1	82.4	78.7	106.0	89.2	106.8	82.8	83.5	71.1	84.4	73.3	92.4	62.7	92.9
0.1	75.0	78.5	81.3	89.7	82.5	107.3	84.7	94.9	75.4	86.2	81.6	94.2	74.6	93.5
0.25	86.6	88.0	82.4	94.9	89.9	107.7	82.1	98.4	83.2	88.7	82.0	91.7	76.7	94.7
0.6	89.7	84.5	89.6	97.6	91.0	108.8	85.3	95.1	85.4	85.8	91.0	99.2	84.8	98.6
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Actual weight complete, grams	133.0	120.7	134.1	110.7	152.7	122.7	143.5	151.7	128.1	146.7	120.0	79.3	123.8	51.3
Mean standard error in grams	3.38	2.42	3.15	1.48	2.90	1.59	2.95	2.21	2.23	1.96	2.50	1.55	1.37	.61

*Yields obtained with complete treatment are taken as 100% and other yields are given in percentage of this yield.

TABLE 3.—*Length of time required for oats to mature in Germany and in Hawaii.*

Soil No.	Growing period, days	
	Germany	Hawaii
39	73	Dec. 15–May 11 (146)
85	73	Mar. 30–June 20 (84)
L4	73	Dec. 15–May 11 (146)
1	73	Oct. 27–Apr. 17 (172)
71	73	Oct. 27–Apr. 17 (172)
109	73	Jan. 25–June 15 (141)
KP5	73	May 4–July 15 (82)

The grain weight of oats grown in Germany was equal to about 40% of the straw plus grain weight. In Hawaii the grain weight was about 20% of the straw plus grain weight.

Reference to the mean standard error and the actual weights obtained with complete fertilization show that, in general, grain plus straw weights were greater in Germany. On the other hand, the yields of replicate pots agreed more closely in Hawaii.

With the exception of soil K. P. 5, the soils investigated contained large quantities of potash available to plants as shown by the Mitscherlich results (Table 2 and Fig. 3). Contrarily, the soils by the Mitscherlich test conducted in Germany and in Hawaii showed that these soils were markedly deficient in available phosphorus and nitrogen. Reference to Fig. 1 shows that results with nitrogen were strikingly similar in Germany and Hawaii.

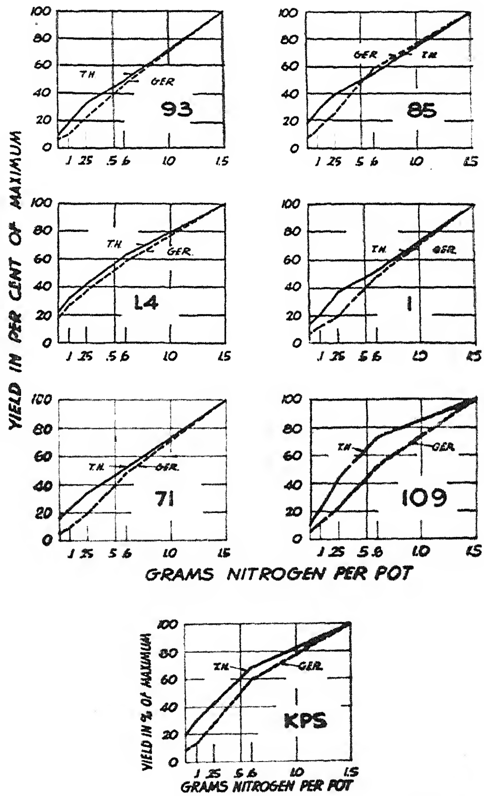

FIG. 1.—Grain plus straw yields on Hawaiian soils in Germany and in Hawaii with varying amounts of nitrogen added.

The results obtained in Hawaii differ from those obtained in Germany in one respect. In Hawaii the relative yields obtained with no phosphorus is far greater than the corresponding yields in Germany on the same soil. From the yields obtained without addition of phosphorus, the amount of root available phosphorus in the soil, the b value, can be calculated by means of the equation $b = \frac{\log A - \log (A - y_o)}{c}$, or by the use of tables (4). In the above equation A = maximum yield with large amounts of fertilizer variable added, expressed as 100%; y° = yield obtained without addition of fertilizer variable, i.e., yield due to nutrient supply in soil, expressed as percentage of maximum yield A; and c = growth factor.

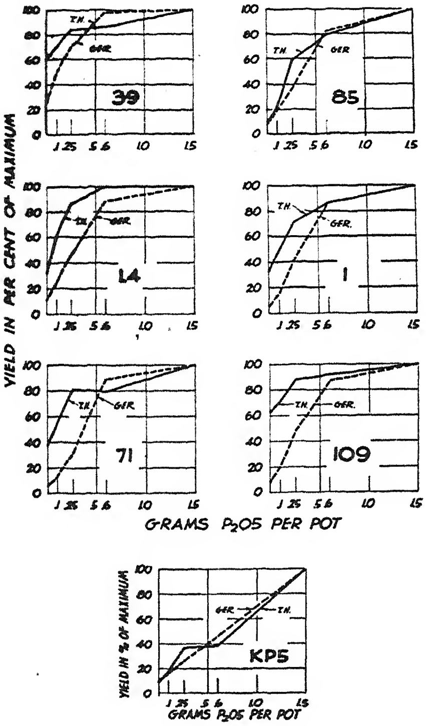

FIG. 2.—Grain plus straw yields on Hawaiian soils in Germany and in Hawaii with varying amounts of phosphorus added.

In calculating these b values, the growth factor c was assumed to be constant and when expressed in units of dz/ha to have the following values: N = 0.122; P_2O_5 = 0.6; and K_2O = 0.93.

The calculated b values, or amounts of available plant food in dz/ha of sand-soil mixture, are given in Table 4.

Inspection of Table 4 shows that the b value or amount of available plant food in the soil was found to be at least twice as great in the Hawaii tests as in the Konigsberg. Two explanations for this difference are given. They are, first, that under the higher Hawaiian temperature plant nutrients were more rapidly made available from the more complex soil materials, thus permitting a greater uptake by the plants in Hawaii in unit time. We know that organic matter conversion and formation of nitrates at a temperature of 25° C in Honolulu will proceed faster than at the lower soil temperatures of Konigsberg. A second explanation is that during the longer growing period of Hawaii of 140 days or over the plants were able to absorb more plant nutrients than in Germany in 73 days.

TABLE 4.—*The amounts in dz/ha of plant food available in sand plus soil mixture as indicated by Mitscherlich.**

Soil	Nitrogen (N)		Phosphorus (P_2O_5)		Potash (K_2O)	
	Germany	Hawaii	Germany	Hawaii	Germany	Hawaii
39	0.21	0.34	0.22	0.69	0.96	0.81
85	0.26	0.70	0.06	0.07	0.72	4.00
L4	0.69	0.89	0.07	0.28	1.04	4.00
1	0.24	0.52	0.04	0.28	0.83	0.84
71	0.18	0.62	0.05	0.35	0.57	0.87
109	0.19	0.37	0.06	0.71	0.61	1.22
KP5	0.32	0.77	0.08	0.07	0.46	1.24
Mean values	0.30	0.60	0.08	0.35	0.74	1.85

*For dz/ha in field soil, multiply values by 6 (5)

The discrepancy between results in Hawaii and in Germany emphasizes that care must be used in the choice of indicator crop. If oats cannot be used in the tropics or sub-tropics, what crop can be used, and furthermore, if oats or some other crop has been selected as an indicator crop in one location, how far away, geographically or climatically, will comparative results be obtained with this same crop on the same soil?

The use of rice as an indicator crop under tropical conditions has been advocated. This crop, however, is sensitive to soil reaction (1).

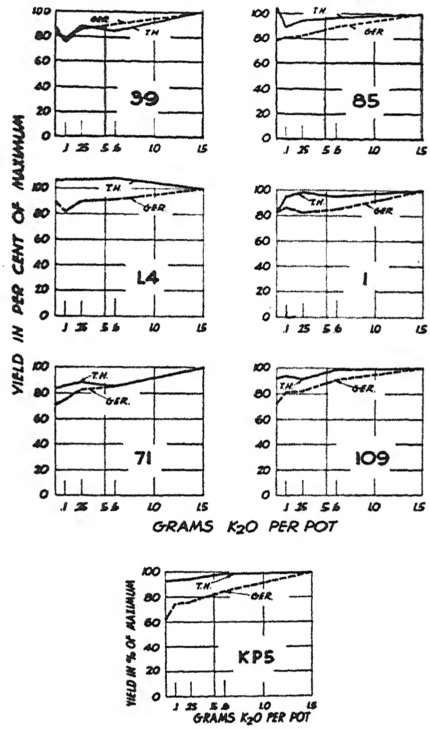

FIG. 3.—With varying amounts of potash added.

CONCLUSION

Seven soil samples from field experiments with pineapples in the Territory of Hawaii were each thoroughly mixed and half of each sent to Professor Mitscherlich, the other half being retained in Hawaii. These soils were all lateritic, contained a high colloid content, and fixed phosphorus readily.

At Konigsberg, Prussia, and also at Honolulu, Mitscherlich pot experiments were conducted as similarly as possible, using Lockows Petkuser oats in both cases.

In general, tests at both places showed the soils to be low in available nitrogen and phosphorus, while almost all soils were well supplied with available potash. The tests in Hawaii indicated that the natural store, or b value, for nitrogen and phosphorus was far greater than found in Germany. This may be explained by the much longer growing period in Hawaii and possibly by the greater rate of nutrient liberation at the higher Honolulu temperatures.

The comparison clearly shows that the indicator crop in this method of soil testing must be selected with particular reference to the locality involved.

LITERATURE CITED

1. Aso, K. Verhalten von Gerste und Reis zur Bodenreaktion. Proc. Second Int. Congress Soil Sci., Comm. 4, 14–18. 1932.
2. Bouyoucos, G. J. Directions for determining the colloidal material of soils by the hydrometer method. Science, 66:16–17. 1927.
3. de'Sigmond, A. A. J. Rapport de la commission pour le mesure de la reaction du sol. Soil Res., 2:148–152. 1930.
4. Mitscherlich, E. A. Die Bestimmung des Dungerbedurfnisses des Bodens. Berlin: Paul Parey, Ed. 3, 1930.
5. ——————. Die Pflanzen physiologische Bodenanalyse. Proc. Second Int. Soc. Soil Sci., Comm. 4, 1–5. 1932.
6. Richter, Charles. The temperature correction in the hydrometer method of mechanical analysis of soils. Soil Science, 31:85–92. 1931.
7. Truog, E. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.
8. Volk, N. J., and E. Truog. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26:537–546. 1934.

THE EFFECT OF SOIL TREATMENT IN STABILIZING YIELDS OF CORN[1]

L. B. Miller and F. C. Bauer[2]

EITHER failure or extreme over-production of a given crop is unfortunate both to farmers as a group and to society in general. The purpose of this paper is to point out the effect of soil treatment and of soil type upon the regularity or stability of corn production over a period of years and on several different soil conditions in Illinois.[3]

SOURCE OF DATA

The crop yield data used in this study were secured from the soil experiment fields operated by the Illinois Agricultural Experiment Station. Most of these fields were established during the years 1910 to 1915. The crops considered in the discussion are those of the 15-year period ending in 1935;[4] hence, the plats were well established by several years of preliminary cropping prior to 1920, the first season from which data for this particular study were used. Substitute crops or other irregularities occurred once during the period on five of the fields and an earlier year's yields were used to complete the 15-year sample. This shift seemed justified because it was possible to secure an income by growing a crop other than corn. The fields were laid out so that each crop of the rotation used was represented each year. Most of the plats were one-tenth acre in size. A few fifth-acre and a few twentieth-acre plats were used.

SOIL TREATMENT

Plats 1, 5, and 10 in each series are untreated. Plats 2, 3, and 4 receive animal manure usually once during each 4-year rotation in amounts equal in weight to the crops removed. Plats 6, 7, 8, and 9 are designated "residue plats." They receive residual plant materials in the form of cornstalks, second growth clover, and a legume catch crop (usually sweet clover) wherever it can be conveniently used in the rotation. Applications of limestone are made as needed to plats 3, 4, 7, 8, and 9 (called the limed plats) and generous applications of rock phosphate were made to plats 4, 8, and 9 (the phosphate plats). Potash is regularly used on plat 9. Expressed by the usual symbols, the soil treatments on the entire series on all fields have been as follows: Plat 1, check; plat 2, M; plat 3, ML; plat 4, MLP; plat 5, check; plat 6, R; plat 7, RL; plat 8, RLP; plat 9, RLPK; and plat 10, check.

[1]Contribution from the Division of Soil Experiment Fields, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication May 4, 1938.

[2]Associate, Soil Experiment Fields, and Professor Soil Fertility, respectively.

[3]A similar paper concerning the wheat crop was presented by the authors in Jour. Amer. Soc. Agron., 29:728–734. 1937.

[4]Yield data published in Illinois Experiment Station Bulletins 273, 280, 296, 305, 327, 347, 370, 382, 398, 402, and 425.

EXPERIMENTAL RESULTS

Corn yields for the 15-year period ending in 1935 have been studied on 17 soil experiment fields in Illinois located as indicated on the map (Fig. 1). These fields are distributed over a range of latitude of more than 300 miles and include many distinctly different soil conditions. The plats were established primarily to study the effect of the soil treatment systems on crop yields and the economical use of land. They now offer, after these many years of cropping, a unique opportunity to study the stability of production on a given soil type, when unfertilized, and also with the various treatments used.

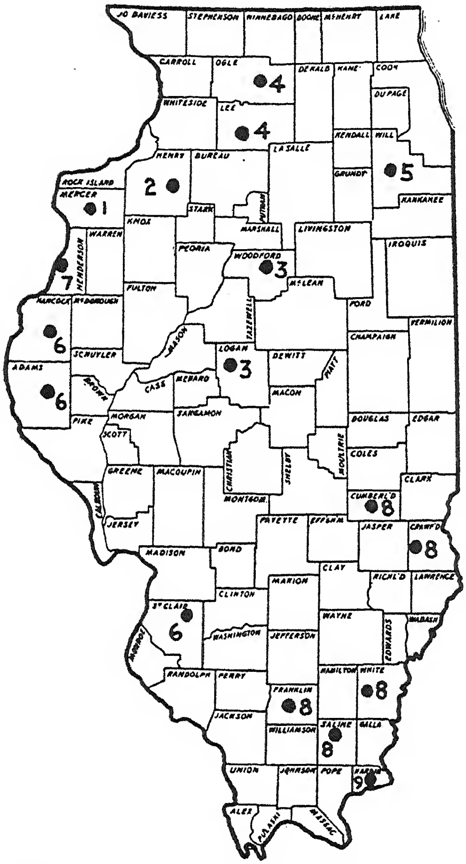

FIG. 1.—Location of the 17 soil experiment fields from which data were used. The numbers indicate the soil group represented by each field.

The 15-year average yield level for each treatment was calculated for each field. The annual variation in yield from this average was determined and reduced to a percentage of the average yield level. The average percentage of fluctuation for the 15-year period was calculated from the annual variation. Annual fluctuations exceeding 25% have been singled out for the purpose of discussion. They were usually distributed with approximately equal frequency above and below the average. The last column in Tables 1, 2, 3, and 4 gives the number of times in which the yields were below the 25% fluctuation level.

Further analysis of the fluctuation, either upward or downward, exceeding 25% of the average yield has been made to determine what portion of the total production is in each of these extreme ranges. This calculation has been reduced from bushels per acre to the basis of bushels per 1,000, and gives a direct measure of the extent to which

TABLE 1.—*Results at Hartsburg in Logan County, dark soil with heavy calcareous subsoil.*

Plat	Soil treatment	Average yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	40–55	55–	
1	O	44.3	17.7	6	6	2	1	—	2
2	M	58.8	12.2	6	8	1	—	—	1
3	ML	66.6	7.4	10	5	—	—	—	0
4	MLP	65.6	10.0	7	8	—	—	—	0
5	O	48.4	16.0	7	5	2	1	—	1
6	R	64.9	13.5	5	9	1	—	—	1
7	RL	68.5	12.6	7	6	2	—	—	1
8	RLP	69.5	11.0	9	4	2	—	—	1
9	RLPK	65.9	12.7	8	5	2	—	—	1
10	O	51.9	14.6	5	8	2	—	—	1

TABLE 2.—*Results at Dixon in Lee County, dark soil with open, noncalcareous subsoil.*

Plat	Soil treatment	Average yield for 15 years, bu.	Average fluctuation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	40–55	55–	
1	O	49.3	17.4	4	8	3	—	—	2
2	M	71.3	15.4	4	9	1	1	—	1
3	ML	76.1	12.9	7	7	—	1	—	0
4	MLP	76.0	12.8	7	7	1	—	—	0
5	O	49.7	21.1	2	9	3	—	1	2
6	R	57.1	18.2	4	7	3	1	—	2
7	RL	66.2	13.6	5	9	1	—	—	0
8	RLP	66.0	16.0	5	9	1	—	—	0
9	RLPK	72.6	14.8	5	9	1	—	—	0
10	O	48.7	19.6	5	5	4	1	—	2

a given soil or treatment has contributed to the production of a corn surplus or of a shortage.

Space does not permit the presentation of all of the data from the 17 fields studied, but Tables 1, 2, 3, and 4 give the summarized material for four widely separated fields which are typical for their respective soil and geographic locations.

The average corn yield fluctuations for the various treatments on the four fields are plotted in Fig. 2 and they indicate graphically the striking differences in stability of corn production for these soil conditions and treatments.

The extent to which each treatment on these four fields contributed to a surplus greater than 125% of its average yield is reported in

TABLE 3.—*Results at Lebanon in St. Clair County, dark soil with impervious noncalcareous subsoil.*

Plat	Soil treat-ment	Aver-age yield for 15 years, bu.	Aver-age fluctu-ation %	Frequency of fluctuations within (percentage) ranges					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	40–55	55–	
1	O	36.7	36.1	3	4	1	4	3	5
2	M	47.2	32.6	1	6	3	2	3	5
3	ML	52.6	23.6	2	7	6	—	—	4
4	MLP	50.7	24.2	3	6	4	2	—	3
5	O	32.0	42.1	2	2	5	1	5	6
6	R	43.5	32.7	1	5	3	5	1	5
7	RL	55.5	23.1	3	6	4	2	—	3
8	RLP	57.3	21.6	4	6	3	1	1	2
9	RLPK	62.9	15.3	5	8	2	—	—	2
10	O	39.7	32.0	3	4	3	1	4	4

TABLE 4.—*Results at Ewing in Franklin County, gray soil with impervious noncalcareous subsoil.*

Plat	Soil treat-ment	Aver-age yield for 15 years, bu.	Aver-age fluctu-ation %	Frequency of fluctuations within (percentage) ranges indicated					Frequency of downward fluctuations exceeding 25%
				0–10	10–25	25–40	50–55	55–	
1	O	8.4	65.9	1	2	2	0	10	7
2	M	22.4	54.2	1	2	1	5	6	7
3	ML	44.6	30.2	1	6	3	4	1	4
4	MLP	45.9	29.1	1	7	4	2	1	4
5	O	9.9	63.6	2	1	1	1	10	6
6	R	11.8	57.3	3	1	1	3	7	6
7	RL	19.2	50.5	1	1	3	3	7	7
8	RLP	22.8	47.6	2	1	4	3	5	7
9	RLPK	47.6	18.1	6	6	2	—	1	2
10*	O	—	—	—	—	—	—	—	—

*Discontinued before 1935.

Table 5. The results are tabulated as bushels per thousand. This calculation was made by singling out those seasons for each treatment when yields exceeded 125% of the 15-year average for that treatment. The number of bushels in excess of the 125% level were totaled and divided by 15 to get the annual average surplus production per acre for the entire period. This per acre figure was reduced to the "per thousand bushel" denominator so that plats having different average acre yields could be directly compared.

A similar procedure was followed to determine the tendency and extent of each plat's failure (below the 75% level) to produce an average crop. This is in line with the method devised by the U. S. Dept.

TABLE 5.—*Surplus production above 125% of average yield per 1,000 bushels.*

Plat	Treatment	Ewing, bu.	Lebanon, bu.	Dixon, bu.	Hartsburg, bu.
1	O	238.1	96.7	19.3	7.9
2	M	165.2	53.2	13.0	0.0
3	ML	28.0	10.1	17.0	0.0
4	MLP	26.1	19.1	7.0	0.0
5	O	209.1	100.9	24.7	17.1
6	R	174.6	44.1	14.2	0.0
7	RL	147.9	11.0	5.1	2.2
8	RLP	152.2	19.0	7.0	1.4
9	RLPK	2.9	0.0	11.6	0.5
10	O	——	69.8	16.0	8.1

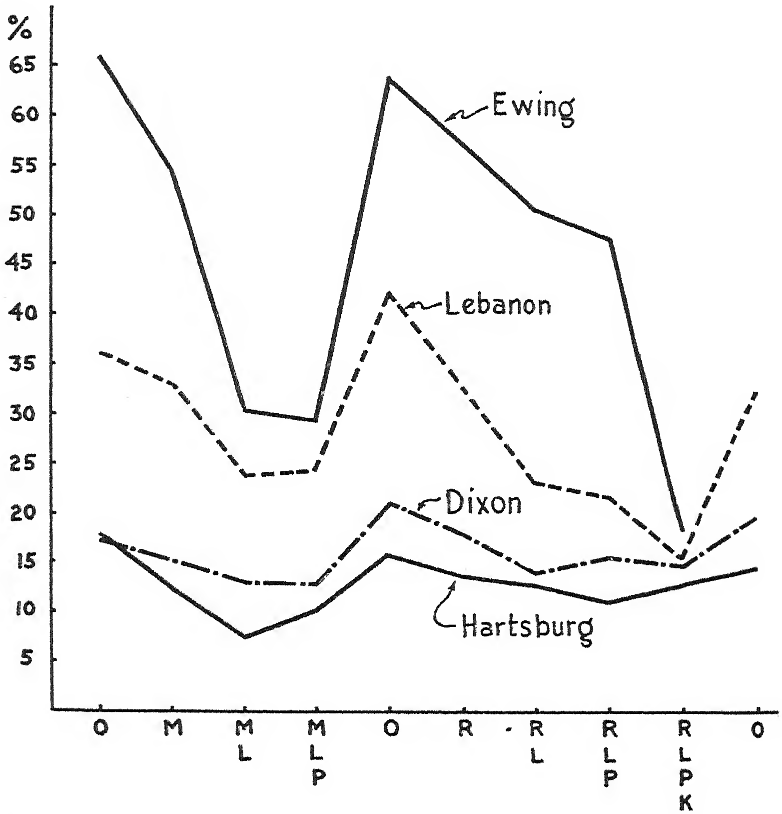

FIG. 2.—Percentage deviation of corn yields, 15-year period. Soil Treatments indicated at bottom of graph.

of Agriculture[5] for the determination of insurance premium rates under the recently suggested plan for crop insurance. The data from any given plat might be thought of as a basis for determining rates for farmers using soil and treatments similar to that of the particular plat. The failures were reduced to the "per thousand bushel" basis as described above, and the results shown in Table 6 are the actual loss costs on all coverage insurance for 75% of average yields.

TABLE 6.—*Loss cost of 75% coverage insurance per 1,000 bushels.*

Plat	Treatment	Ewing, bu.	Lebanon, bu.	Dixon, bu.	Hartsburg, bu.
1	O	198.9	83.7	8.7	17.8
2	M	153.1	64.2	1.8	7.0
3	ML	72.9	22.4	0.0	0.0
4	MLP	66.4	27.4	0.0	0.0
5	O	210.1	104.1	7.8	8.1
6	R	188.1	69.0	12.8	7.4
7	RL	120.3	40.4	0.0	1.0
8	RLP	101.3	30.2	0.0	3.7
9	RLPK	34.7	13.1	0.0	9.1
10	O	——	57.2	19.5	0.4

Perhaps this can be made clearer by the use of an illustration involving two farmers operating land such as that of the Ewing field. Let us assume that farmer No. 1 follows the method of plat 1 (no treatment) and farmer No. 2 uses the soil treatment of plat 4 (MLP). Each man has insurance which guarantees him a 75% crop and whenever his yield falls below that level he is to receive payment in bushels of corn sufficient to bring his yield up to the 75% level. To secure this protection he pays premiums, also in corn, and in amount equal to the indemnities he would collect. The premium or insurance cost of farmer No. 1 (plat 1), based on 15 years' results at Ewing, would have been 198.9 bushels of corn out of every 1,000 bushels he had grown, while the insurance cost of farmer No. 2 (plat 4) would have been 66.4 bushels per thousand, or approximately one-third as great. The loss cost of 75% coverage insurance on this basis for all plats at Ewing and on three additional fields are reported in Table 6 and give a good measure of the risk associated with growing corn on the different soils as they were treated. There were two plats at Hartsburg and five plats at Dixon on which production never fell below the 75% average during the entire 15-year period.

The soils of the 17 fields used in this study are representative of nine soil groups. These groups, together with the names of the fields in each, are as follows:

Group 1. Dark soils with heavy, noncalcareous subsoils.
Aledo, Mercer County.

Group 2. Dark soils with noncalcareous subsoils.
Kewanee, Henry County.

[5] 75th Congress, 1st Session, House Document No. 150.

Group 3. Dark soils with heavy calcareous subsoils.
Hartsburg, Logan County.
Minonk, Woodford County.

Group 4. Dark soils with open noncalcareous subsoils.
Dixon, Lee County.
Mt. Morris, Ogle County.

Group 5. Dark soils with heavy, impervious, calcareous subsoils.
Joliet, Will County.

Group 6. Dark soils with impervious, noncalcareous subsoils.
Carthage, Hancock County.
Clayton, Adams County.
Lebanon, St. Clair County.

Group 7. Sandy loams and sands.
Oquawka, Henderson County.

Group 8. Gray and yellowish-gray soils with impervious noncalcareous subsoils.
Enfield, White County.
Ewing, Franklin County.
Oblong, Crawford County
Raleigh, Saline County.
Toledo, Cumberland County.

Group 9. Hilly, forest, orchard and pasture land.
Elizabethtown, Hardin County.

It is unfortunate that some of the soil groups are represented by only one field. However, the similarity of performance of individual fields within those groups having more than one representative indicates that each field is a fairly reliable sample. The average yields and percentages of fluctuation for the soil groups are given in Tables 7 and 8. The groups are arranged in the order of decreasing yields on the untreated plats.

DISCUSSION OF RESULTS

Corn grown on fertile dark-colored soils was consistent in producing high yields. The results secured at Hartsburg (Table 1) and Dixon (Table 2) are typical of the better corn-belt soils of Illinois. The average percentage of fluctuation was low even on the untreated plats and was reduced approximately one-fourth by treatment. During the 15-year period at Dixon the greatest downward fluctuation on the limed plats was 24.5%. In contrast to this each of the untreated plats had two seasons when downward fluctuation exceeded 25% with a maximum of 40.9% on plat 10.

The soil at Lebanon in St. Clair County is also dark in color but has an impervious subsoil and, while it frequently produced high yields of corn, it was much less reliable in this respect than the better-drained dark-colored soils of the central and northern part of the state. Another factor which contributed to irregular production at Lebanon was the rather frequent and serious damage done by chinch bugs. Corn yields on plat 9 (RLPK) showed the least fluctuation, the

TABLE 7.—*Yields of corn in bushels per acre for soil groups, 15-year average.*

Soil treatment	Soil group numbers								
	2	1	4	3	6	5	7	8	9
O	56.0	49.4	50.1	46.7	37.7	33.3	20.9	16.0	—†
M	71.8	65.5	69.8	60.3	52.6	45.6	30.7	27.8	21.6
ML	76.5	68.5	75.3	65.0	61.0	51.3	42.8	44.7	38.1
MLP	77.5	68.5	75.2	64.2	62.1	50.9	43.5	45.3	42.3
O	56.3	54.8	48.2	48.8	37.8	31.2	22.1	15.4	10.3
R	64.0	63.5	56.0	62.9	49.9	35.7	25.1	19.0	13.5
RL	70.2	75.1	66.7	66.0	61.7	39.9	40.1	28.1	33.2
RLP	73.6	76.7	67.2	67.4	63.0	46.9	40.3	30.6	42.3
RLPK	75.0*	78.5	72.2	64.5	67.7	50.1	41.0	45.8	43.1
O	—†	54.1	47.4	49.0	42.2	31.6	21.9	—†	—†
Average of untreated plats	56.1	52.8	48.6	48.2	39.2	32.0	21.6	15.7	10.3

*Chinch bug injury.
†Plat discontinued before 1935.

TABLE 8.—*Yield fluctuations for soil groups, 15-year average percentages.*

Soil treatment	Soil group numbers								
	2	1	4	3	6	5	7	8	9
O	22.0	22.1	19.7	15.8	26.9	25.0	42.3	50.1	—†
M	14.4	25.1	16.9	13.0	24.0	20.3	33.5	38.1	52.5
ML	15.0	21.0	12.9	9.9	18.7	14.9	33.4	24.8	31.9
MLP	14.4	20.5	13.1	12.3	19.0	15.9	35.3	24.9	19.8
O	19.8	21.0	21.2	17.0	29.9	27.8	46.5	46.3	75.6
R	17.3	19.4	17.8	14.7	24.6	25.8	41.2	39.1	61.7
RL	18.3	11.2	15.3	13.9	20.4	18.5	36.2	33.4	25.9
RLP	17.1	11.3	16.3	14.0	19.6	17.1	39.0	33.2	21.9
RLPK	19.3*	13.8	17.3	14.4	17.2	16.5	39.5	20.8	25.6
O	—†	19.9	18.9	16.9	24.7	30.4	47.1	—†	—†
Average of untreated plats	20.9	21.0	19.9	16.6	27.2	27.7	45.3	48.2	75.6

*Chinch bug injury.
†Plat discontinued before 1935.

average being only 15.3%. The average fluctuation on the untreated land was 36.7%, while the average for the limed plats was 21.6%. On the untreated plats downward fluctuations exceeding 25% occurred five times during the 15 years. The average on the limed plats was slightly less than three such fluctuations during the period.

At Ewing (Table 4) which is typical of the gray, poorly-drained soils of group 8, the yields on untreated land were very low and fluctuated greatly, the average being 64.7% with downward variations greater than 25% occurring during nearly half of the seasons. However, an average yield of 47.6 bushels an acre was secured on plat 9

(RLPK) with an average fluctuation of only 18.1% and but two seasons when the downward fluctuation was more than 25%. Plat 4 (MLP) ranked next to plat 9 in this respect with four low-yield seasons and an average variation of 29.1%.

On hilly land at Elizabethtown in Hardin County the use of limestone with phosphate and organic matter supplied either as stable manure (MLP) or as green manure (RLP) greatly increased the reliability of corn production. However, these better plats were considerably lower in both yield and dependability than was the case on the untreated dark-colored soils of the corn belt.

Corn yields on sandy land at Oquawka were approximately doubled by the use of limestone and organic matter, but fluctuation was high, even on the best yielding plats. Plat 4 (MLP) produced 43.5 bushels an acre for the highest average yield, but had an average fluctuation of 35.3%.

The average production of surplus per thousand bushels for each plat, as described above, is recorded in Table 5. The greatest variation in this respect between plats on the same field was at Ewing, where, on the first untreated plat, 238.1 bushels per thousand or more than one-fifth of the crop was in the surplus group. In contrast to this, only 2.9 bushels of surplus per thousand was produced on plat 9 (RLPK), there being only one crop on this plat which yielded in excess of 125% of the average and that excess was only 2.1 bushels. Production on one of the untreated plats at Ewing was in excess of the 125% level six times during the 15 years, while the other untreated plat had five such excess yields.

At Lebanon no surplus greater than 25% was produced on plat 9 (RLPK). In contrast to this, the average surplus production of the three untreated plats was 89.1 bushels per thousand.

On the better dark-colored soils represented by Dixon and Hartsburg, there was very little surplus production of corn above the 125% average yield level, the average on untreated land being only 20 bushels per thousand at the former and 11 bushels per thousand at the latter field. Treatments on both of these fields reduced, even below this low level, the number of surplus bushels produced. At Hartsburg four of the treated plats produced no surplus yields during the entire 15 years observed.

The data in Table 5 have shown the extent to which soils and treatments have contributed to excessive corn production above a yield level 25% higher than the average of each plat. Table 6 may be thought of as being the converse of Table 5 in so far as it shows the extent to which production on a given plat failed by more than 25% to equal the average for that plat. The bushels reported in Table 6 might, as suggested above, be thought of as appropriate 75% coverage insurance premiums per thousand bushels of corn grown with the various soils and treatments.

By totaling the items from Tables 5 and 6 for a given plat, we have a measure, based on 15 years' results, of the bushels per thousand which that plat contributed to all yield variations exceeding 25% of its 15-year average yield.

GENERAL COMMENTS

During the 15-year period studied a number of irregularities in procedure have occurred which should be recognized. The crop rotation was altered slightly on some of the fields and a few changes were made in varieties of corn used. In some instances the method and amount of fertilizer application was varied but the same general treatment for each plat was continued throughout the entire 15-year period and for several seasons prior to 1920, the first season from which data were used. This preliminary cropping tended to establish the yield for each treatment at a level near which it was maintained during the 15 years studied. Undoubtedly there were some unnoticed irregularities due to damage by rodents or insects or other causes on portions of plats or fields. Where irregularities were noticed, they were either corrected or noted in the tables.

No attempt has been made in this paper to correlate yield irregularities with weather conditions or other specific factors which may have caused them.

CONCLUSIONS

1. The fertile, dark-colored, corn belt soils produced high yields of corn with a high degree of regularity from year to year.
2. Corn production was very irregular on untreated land of low fertility.
3. Stability of corn production was greatly improved by soil treatment on all of the poor or moderately fertile soils studied except the sandy soil where treatment raised the yield level but caused only a slight reduction in yield fluctuation.
4. The most successful treatments on the poor and intermediate soils failed to bring either their average yield or regularity up to the level of the treated plats on the better soils. However, in many cases their performance did excel that of the untreated plats of the better soil groups.
5. Surpluses and losses exceeding 25% of the average yield were produced at least once during the 15 years on all untreated land, even on the best soils studied.
6. Surpluses and also losses exceeding 25% were so great on the poorer untreated land that in some cases they totaled more than one-fifth of the entire production.
7. Good soil and good farming methods are in themselves very good corn crop insurance under Illinois conditions.
8. Farmers who practice good farming methods will have few seasons of extreme surplus yields and are in a good position to predict the amount of their corn production.

AGRONOMIC AFFAIRS

THE SOIL SCIENCE SOCIETY OF AMERICA

A call for papers for the annual meeting of the Soil Science Society of America, November 15 to 18, 1938, has been issued by the Secretary, Dr. W. A. Albrecht of the University of Missouri. Titles of papers to be presented at the meeting should be in the hands of the respective Section chairmen at an early date. The chairmen and their addresses are as follows:

Section I. Soil Physics

L. A. RICHARDS................Iowa State College, Ames, Iowa.

Section II. Soil Chemistry

E. E. DETURK................Univ. of Illinois, Urbana, Illinois.

Section III. Soil Microbiology

N. R. SMITH.............Bur. Plant Industry, Washington, D. C.

Section IV. Soil Fertility

H. J. HARPER........Oklahoma A. & M. College, Stillwater, Okla.

Section V. Soil Morphology

W. E. HEARN.............Bur. Chem. & Soils, Washington, D. C.

Section VI. Soil Technology

E. A. NORTON.......Soil Conservation Service, Des Moines, Iowa.

Papers for the PROCEEDINGS will be limited to 5,000 words, with a surcharge for all beyond this figure. Abstracts will also be desired in advance of the meeting. Communication with your Section chairman will facilitate the placement of your paper on the program.

SUMMER MEETING OF CORN BELT SECTION

ABOUT 150 agronomists, representing 14 states, the U. S. Dept. of Agriculture, and Australia, participated in the summer meeting of the Corn Belt Section of the Society at the University of Missouri on June 22 and 23. Several arrived in time to witness the celebration of the fiftieth anniversary of the founding of the Missouri Experiment Station on June 21.

One day of the meeting was spent inspecting agronomic work in progress at Columbia, while the second day was devoted to a tour of outlying experimental tracts.

An invitation from the Ohio Experiment Station to hold the 1939 meeting in that state was accepted.

NEWS ITEMS

TWO HUNDRED farmers from all sections of Florida attended the recent All-Florida Pasture Conference at the University of Florida

College of Agriculture in Gainesville. The first conference of its kind in Florida, it was held for the purpose of bringing together farmers, agricultural workers, and farm finance agencies to work out a program for pasture development in the state. Outstanding features included a tour of pasture and live-stock experimental work being done by the Florida Agricultural Experiment Station, discussions and addresses by Dr. H. Harold Hume, Experiment Station research official; H. R. Smalley, agronomist for the National Fertilizer Association; H. S. Johnson, Farm Credit Administration official; and others. Dean Wilmon Newell presided at the conference.

Doctor M. F. Miller, Dean of the Missouri College of Agriculture and Director of the Experiment Station, was given the honorary degree of Doctor of Science by the Kansas State College at the seventy-fifth anniversary commencement of that institution.

For the first time in the history of this country an American peat moss, produced on a commercial scale, will be placed on the market. A company known as the American Peat Company has begun operations on a 1,300-acre highmoor sphagnum peat bog known as the Denbo Heath and located near the town of Deblois, north of Cherryfield, Maine.

Doctor F. D. Richey, formerly Chief of the Bureau of Plant Industry and a past President of the Society, is now located at Ashville, Ohio, where he is engaged in the commercial production of corned hybrids.

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EFFECT OF STRAINS OF NODULE BACTERIA AND LIME ON THE RESPONSE OF SOYBEANS TO ARTIFICIAL INOCULATION[1]

CHAS. F. BRISCOE AND W. B. ANDREWS[2]

THE carbohydrate-nitrogen relation in symbiotic nitrogen fixation has been investigated by Wilson (13)[3], Umbreit and Fred (11), and others. The greatest fixation of elemental nitrogen takes place where the assimilation of CO_2 and nitrogen are in balance which gives a medium carbohydrate-low nitrogen plant. Wilson suggests that strains of organisms may vary in response to a given carbohydrate-nitrogen relation in the plant. If they do, inoculation tests conducted in the greenhouse and at different seasons of the year may not be applicable in the field.

Baldwin and Hofer (2) found that certain strains of bacteria produced nodules only when there was a high carbohydrate-nitrogen relation (spring) in the plant, while one strain produced nodules on both the winter and spring plantings. They also found that the response of strains of organisms to the carbohydrate-nitrogen relation was modified by cultivation on media containing different forms of nitrogen.

Orcutt and Fred (8) found that partial shading of soybeans grown in nitrogen-free sand caused them to fix atmospheric nitrogen where they failed to fix nitrogen in the sunlight of early summer. Variations in the light intensity and rainfall in different sections of the country may produce different carbohydrate-nitrogen relations in plants. If different carbohydrate-nitrogen relations exist in one species of plants grown in different sections of the country, the work of Baldwin and Hofer (2) indicates that variations in the effectivenss of strains of Rhizobia may exist when used under the different climatic conditions.

Variations in the inoculation of varieties of soybeans by a given culture of Rhizobia have been pointed out by Voores (14), who found that the Haberlandt failed to produce nodules under the same inoculation conditions that Mikado, Peking, Tarheel Black, Brown, and Auburn varieties produced an abundance of nodules. Similarly, Morse (7) found that the Acme and Tokio varieties failed to produce nodules where Mammoth produced an abundance of nodules.

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[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication April 29, 1938.

[2]Bacteriologist and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 718.

On the basis of the research work reported previous to 1932, Fred, Baldwin and McCoy (4) placed cowpeas and soybeans in different cross inoculation groups. Soybeans have been observed to produce nodules in many cases where they have not been grown previously. Leonard (5), Walker (12), Carroll (3), Reed and Baldwin (9), and Sears and Carroll (10) have found that cross inoculation takes place between the cowpea and the soybean groups. In general, soybean strains of Rhizobia produce good nodulation on cowpeas but only a few strains of cowpea Rhizobia produce nodules on soybeans.

Variations in the effectiveness of strains of nodule bacteria have been reported by many investigators, including Fred, Baldwin, and McCoy (4). Recently, McCalla (6) found that abnormal cultures of nodule bacteria may be produced from normal cultures when grown on a culture medium lacking in calcium. He concludes that, "In the presence of an ample supply of calcium, normal legume bacteria remained normal and abnormal or so-called variant forms became normal. All these, after growth with ample calcium, gave good nodulation on plants supplied with calcium. In the absence of calcium, the normal legume bacteria became abnormal and the abnormal forms remained abnormal; both failed to nodulate the host plant." The pH of the culture medium lacking calcium was maintained by the addition of barium.

That strains of nodule bacteria vary in their lime requirement was shown by Alway and Ness (1), who found that pure cultures of alfalfa nodule bacteria required more lime in the establishment of stands of alfalfa than do soil cultures.

The purpose of this paper is to present preliminary data on (a) variations in the response of varieties of soybeans to strains of nodule bacteria, (b) the response of one variety of soybeans grown in Mississippi to strains of Rhizobia from other sections of the country, (c) the response of strains of Rhizobia to lime, and (d) the inoculation of soybeans by cowpea Rhizobia.

EXPERIMENTAL

The response of Mammoth Yellow and Laredo soybeans to lime and to a good and a poor strain of nodule bacteria was determined in the field on Lufkin clay, using 1/60 acre plats with four rows 3½ feet apart. All plats received 600 pounds of 0–8–4 fertilizer per acre and the limed plats received 2 tons of ground limestone per acre. The air-dry yields are reported in Table 1. The soybeans were harvested in the full pod stage. Although the Laredo lost more leaves than the Mammoth Yellow, the results are comparable.

Sixteen strains of good soybean nodule bacteria were obtained from various agricultural experiment stations, as follows: Iowa, 3; Florida, 2; U. S. Dept. of Agriculture, 7; and Mississippi, 3. In addition one good strain of cowpea nodule bacteria was obtained from New York and one from Wisconsin. These cultures were used to inoculate Mammoth Yellow soybeans on limed and unlimed Lufkin clay soil. The pH of the untreated soil was 4.40. All plats received 600 pounds of 0–8–4 fertilizer per acre in the drill and the limed plats received 400 pounds of dolomite per acre in the drill. The plats were one row, 3½ feet wide, and 1/400 acre in size. There were 6 plats of each treatment except the check which had 18 plats. The soybeans were cultivated to keep down the weeds.

TABLE 1.—*The effect of the variety of soybean and lime on the effectiveness of strain of root nodule bacteria.*

Variety	Kind of nodule bacteria	Yield in pounds per acre			
		Limed	Unlimed	Increase due to lime	Odds
Mammoth Yellow	Poor	3,440	1,800	1,640	18
Laredo..........	Poor	1,560	1,120	440	8
Mammoth Yellow	Good	4,310	3,000	1,310	81
Laredo..........	Good	3,020	1,020	2,000	25
Mammoth Yellow	None	1,990	1,130	860	272
Laredo..........	None	1,670	1,130	540	265
Increase Over no Inoculation*					
Mammoth Yellow	Poor	1,400	720	—	—
Odds............		15	88	—	—
Laredo..........	Poor	−40	60	—	—
Odds............		3	9	—	—
Mammoth Yellow	Good	2,213	1,693	—	—
Odds............		80	106	—	—
Laredo..........	Good	1,293	−213	—	—
Odds............		65	72	—	—

*These increases are not derived directly from the above data because, where possible, advantage was taken of an increase in number of plats.

The soybeans were harvested in the small pod stage and green weights were obtained and converted to air-dry weights per acre. Total nitrogen determinations were made on the air-dry hay according to the methods of official agricultural chemists. The data are reported in Tables 2 and 3.

Previous to the field testing the strains of bacteria were grown in the laboratory on low-nitrogen media containing ample calcium. The soybean seed were measured out for each row and an excess of the different cultures was applied after which the seed were covered. Very few nodules occurred on the unlimed checks; however, the limed checks produced quite a few nodules.

In the first experiment reported Student's odds were calculated. In the other experiment standard errors of the increases were calculated from paired differences.

RESULTS AND DISCUSSION

INFLUENCE OF VARIETY ON THE EFFECTIVENESS OF STRAINS OF NODULE BACTERIA

The good and the poor strains of soybean nodule bacteria used in the experiment reported in Table 1 were obtained from the University of Wisconsin. The good strain has given uniformly good results. The poor strain has been used in experiments in the greenhouse where it has given uniformly poor results. On the unlimed soil the Laredo showed no response to either the good or the poor strain of

TABLE 2.—*The response of soybeans to strains of root nodule bacteria and lime.*

Culture		Unlimed soil			Limed soil		
No.	Source	Increase over check, pounds air-dry hay per acre	Nitrogen %	Increase over check, pounds nitrogen per acre	Increase over check, pounds air-dry hay per acre	Nitrogen %	Increase over check, pounds nitrogen per acre
512	Laredo soybean, Miss.	877±297*	1.89±0.066	24.1±5.73	520±303	2.05±0.079	19.9± 6.27
522	Pimpu soybean, Iowa	760±365	1.77±0.097	18.5±7.87	404±252	1.89±0.056	12.3± 7.20
523	Soysota soybean, Iowa	529±233	1.48±0.153	8.7±8.67	296±176	1.61±0.028	4.1± 5.60
524	Midwest soybean, Va.	39±340	1.42±0.079	1.5±6.67	337±260	1.63±0.097	3.7± 6.00
525	Virginia soybean, Va.	371±411	1.52±0.140	5.5±8.13	424±243	1.80±0.103	9.5± 7.47
526	Guelph soybean, Va.	237±361	1.45±0.103	3.9±6.27	603±209	1.68±0.113	8.7± 7.33
527	Tokio soybean, Va.	587±437	1.63±0.153	12.0±9.73	843±239	1.95±0.088	23.2± 6.13
528	Haberlandt soybean, D. C.	157±245	1.44±0.121	0.9±4.80	191±263	1.73±0.047	4.8± 6.13
529	Laredo soybean, Va.	183±375	1.41±0.080	0.1±1.07	53±327	1.67±0.241	1.5± 7.20
531	Tarheel soybean, Va.	523±363	1.75±0.166	16.4±8.13	509±279	1.83±0.155	0.1± 7.73
532	Wilson soybean, D. C.	524±355	1.60±0.062	10.1±6.67	477±288	1.75±0.114	9.2± 5.07
533	Itosan soybean, Va.	323±337	1.39±0.118	3.2±7.33	183±269	1.69±0.117	2.8± 4.40
534	Soybean, Florida	423±341	1.50±0.137	7.2±5.33	237±308	1.68±0.110	6.1± 7.47
536	Soybean, Florida	687±379	1.78±0.105	17.5±7.87	564±282	1.81±0.068	13.5± 7.20
537	Mamredo soybean, Miss.	611±298	1.84±0.134	18.3±8.53	404±147	2.02±0.130	18.4± 4.53
541	Mamredo soybean, Miss.	271±346	1.71±0.138	8.8±6.53	120±104	1.73±0.178	6.1± 4.40
CP15	Cowpea, New York	673±333	1.71±0.227	17.1±6.93	449±154	1.81±0.178	11.9± 4.53
CP24	Cowpea, Wis.	313±315	1.45±0.119	3.7±4.80	183±184	1.89±0.093	9.7±20.4
Check		1920±401	1.47±0.100	29.6±7.47	2629±389	1.56±0.142	45.3±10.93

*Standard error.

nodule bacteria, whereas the yield of the Mammoth Yellow was increased 720 pounds and 1,693 pounds per acre by the poor and the good strain, respectively. These increases are statistically significant. On the limed soil the Laredo was not benefited by the poor strain and the good strain increased its yield 1,293 pounds per acre, while the yield of the Mammoth Yellow was increased 1,400 pounds and 2,213 pounds per acre by the poor and the good strain, respectively. The former increase is not statistically significant; the latter is.

TABLE 3.—*The effect of lime on the yield, nitrogen content, and total nitrogen where different strains of root nodule were applied.*

Culture		Increase due to lime		
No.	Source	Pounds air-dry hay per acre	Nitrogen %	Total nitrogen, pounds per acre
512	Laredo soybean, Miss.	444±278*	0.18±0.104	11.5±6.13
522	Pimpu soybean, Iowa	356±287	0.12±0.083	9.5±6.67
523	Soysota soybean, Iowa	477±232	0.22±0.102	12.5±2.27
524	Midwest soybean, Va.	1013±355	0.21±0.120	20.9±6.53
525	Virginia soybean, Va.	764±277	0.28±0.167	19.6±7.73
526	Guelph soybean, Va.	1164±242	0.23±0.170	22.7±4.40
527	Tokio soybean, Va.	967±255	0.32±0.166	26.9±7.87
528	Haberlandt soybean, D. C.	744±305	0.28±0.070	19.6±7.47
529	Laredo soybean, Va.	583±217	0.26±0.119	17.7±6.67
531	Tarheel soybean, Va.	697±245	0.01±0.315	12.5±11.60
532	Wilson soybean, D. C.	664±187	0.14±0.149	14.8±5.73
533	Itosan soybean, Va.	571±163	0.31±0.143	18.8±5.33
534	Soybean, Florida	517±225	0.19±0.119	14.8±4.53
536	Soybean, Florida	589±165	0.03±0.106	11.6±5.33
537	Mamredo soybean, Miss.	504±240	0.18±0.207	15.9±10.80
541	Mamredo soybean, Miss.	560±282	0.02±0.141	13.1±9.20
CP15	Cowpea, New York	487±202	0.06±0.220	9.7±9.33
CP24	Cowpea, Wis.	651±140	0.44±0.044	21.7±4.13
Check	....	688±165	0.15±0.082	15.7±3.40

*Standard error.

The response of Laredo to the poor strain of nodule bacteria is in agreement with the results obtained in greenhouse experiments at Mississippi Experiment Station. The response of Mammoth Yellow to the poor strain is contrary to that of Laredo. The difference in the response of Laredo and Mammoth Yellow to the good and poor strains of bacteria is in agreement with the data of Voores (14) and Morse (7), who found that certain varieties of soybeans failed to produce nodules where other varieties produced an abundance of nodules.

RESPONSE OF SOYBEANS TO GOOD STRAINS OF NODULE BACTERIA

Unlimed soil.—The 16 strains of soybean nodule bacteria used in this experiment were obtained from different sections of the United States. On the unlimed soil (Table 2) there were only four strains of nodule bacteria which produced yields significantly greater than the check. They were Nos. 512, 522, 523, and 537. Out of the 16 strains of soybean nodule bacteria used, the nitrogen content of the soybeans

was lower, but not significantly lower, than the check where five of them were used. Seven strains increased the nitrogen content slightly, but not significantly. Only four strains increased the nitrogen content of the soybeans significantly. They are Nos. 512, 522, 536, and 537. Three of the four strains which increased the yield significantly also increased the nitrogen content significantly. Significance as used in this paper is based upon the difference being twice its standard error.

The effect of the inoculation can be interpreted more easily from the combination of the nitrogen content and the yield, which gives the total nitrogen in the soybeans. The data in Table 2 show that 5 of the 16 soybean strains produced increases in total nitrogen which were significantly greater than the total nitrogen of the check. Strain No. 512 had 24.1 ± 5.73 pounds of total nitrogen more than the check. The nitrogen fixed by this strain was significantly greater than that fixed by nine other strains.

Limed soil.—On the limed soil 4 of the 16 strains of soybean nodule bacteria increased the yield significantly. The other 12 strains increased the yield from 53 pounds to 520 pounds per acre and significance was approached by some of them. Four strains increased the nitrogen content of the soybeans significantly. Strains Nos. 527 and 537 increased both the yield and nitrogen content significantly.

Strain No. 537 was the only strain which increased both the yield and the nitrogen content of the soybeans significantly on both the limed and the unlimed soil. This strain was isolated from Mamredo soybeans in Mississippi. Strains Nos. 512 and 522 increased the yield and nitrogen content of the soybeans on the unlimed soil significantly and the nitrogent content on the limed soil. Strain No. 512 was isolated from Laredo soybeans in Mississippi; No. 522 from Pimpu soybeans in Iowa. Strain No. 527 was one of the best strains on the limed soil. It was isolated from Tokio in Virginia.

Three of the 16 strains used in this test were isolated in Mississippi and this was the first field test in which they have been used. The other 13 were strains which had proved their value in other states. The best strain in the test was Mississippi No. 537. Mississippi strain No. 512 was in the second best group with Iowa No. 522. Mississippi strain No. 541 was one of the poorer strains. These data indicate that good strains of nodule bacteria isolated locally may be more efficient than good strains from other climates.

Even though there were six replications of each treatment, the standard errors were very large.

On the limed soil 4 of the 16 strains produced increases in nitrogen content which are significantly greater than the check. The total nitrogen fixed by strain No. 527 is significantly greater than that fixed by 9 of the other 15 strains used in the test.

RESPONSE OF SOYBEANS TO LIME WHEN INOCULATED WITH DIFFERENT STRAINS OF NODULE BACTERIA

Alway and Ness (1) found that pure cultures of nodule bacteria are more sensitive to a deficiency of calcium than are soil cultures when used to inoculate alfalfa. The data in Table 3 show that lime

increased the yield of the check 688±165 pounds per acre. Lime increased the yield of soybeans where the different strains of bacteria were used from 356±287 to 1,164±242 pounds per acre. However, in no case was there an increase which was significantly greater than the increase in yield obtained without inoculation.

The increases in nitrogen content due to the application of lime are also reported in Table 3. The nitrogen content of the check was increased 0.15±0.082% by the application of lime. The nitrogen content of the soybeans receiving cowpea No. 24 bacteria was increased 0.44±0.044% by the addition of lime. The cowpea No. 24 strain of nodule bacteria showed a greater response to lime than any strain of bacteria used in the test. It should be borne in mind that on the unlimed soil this strain did not increase the nitrogen content of the soybeans, whereas many of the other strains produced good increases in the nitrogen content on the unlimed soil. The increase in nitrogen content due to the application of lime where this cowpea No. 24 was used, was significantly greater than the increase obtained where strains Nos. 541, 536, 535, 522, 512, and 502 were used.

The increase in total nitrogen due to the application of lime was greater where strain No. 527 was used than where any other strain was used. The increases in total nitrogen varied from 9.5±6.67 to 26.9±7.87. The differences between the strains are not statistically significant.

The data in Table 1 show that lime increased the yield of Mammoth Yellow soybeans 860, 1,640, and 1,310 pounds per acre where none, poor, and good nodule bacteria were used, respectively. The corresponding increases where Laredo was grown were 540, 440, and 2,000 pounds per acre, respectively.

INOCULATION OF SOYBEANS BY COWPEA NODULE BACTERIA

Leonard (5) reported that good results were obtained when a soybean strain of Rhizobia was used to inoculate both soybeans and cowpeas. The results when a cowpea strain was used were quite different. The cowpea strain usually failed to produce nodules on soybeans. Other investigators report similar results.

The cowpea strains of nodule bacteria used in this experiment were obtained from the Wisconsin and the New York Agricultural Experiment Stations. The cowpea No. 15 strain from New York increased the yield of Mammoth Yellow soybeans (Table 2) 673±333 pounds and 449±154 pounds per acre and the nitrogen content from 1.47±0.100% to 1.71±0.227% and from 1.56±0.142% to 1.81±0.178% on unlimed and limed soil, respectively. The increases in yield are statistically significant; the increases in nitrogen content are not. The cowpea strain from Wisconsin increased the nitrogen content significantly on the limed soil; however, the increases in yield obtained on both the limed and the unlimed soil were not significant where this strain was applied and the nitrogen content of the soybeans on the unlimed soil was not increased by this strain.

If the data presented by Leonard (5) are combined with those presented in this paper, it is evident that good inoculation of soybeans or

cowpeas may be obtained by a suitable strain from either the cowpea or the soybean cross inoculation group. If these data are combined with those presented above which show that different varieties of soybeans respond differently to different strains of nodule bacteria, the evidence indicates that differences between the soybean and the cowpea cross inoculation groups are probably similar to those existing within varieties of soybeans. The evidence presented raises the question, Is the separation of soybeans and cowpeas into different cross-inoculation groups justified? But it is evident that major emphasis should be placed upon additional experiments to determine the effectiveness of strains for different varieties of soybeans and species of the cowpea group rather than on an effort to combine the groups.

SUMMARY AND CONCLUSIONS

The response of Mammoth Yellow and Laredo soybeans to a good and to a poor strain of soybean nodule bacteria was determined in the field on limed and unlimed soil. Sixteen strains of good soybean nodule bacteria and two strains of cowpea root nodule bacteria were obtained from different sections of the country and used to inoculate Mammoth Yellow soybeans in the field on limed and unlimed soil. There were six replications of each treatment in the latter test. The standard error of the data obtained was quite large even though an apparently fairly uniform soil was used. The work is to be repeated to check the conclusions more closely. From the data presented the following conclusions are drawn:

1. Variations in the response of Mammoth Yellow and Laredo soybeans to strains of nodule bacteria are probably as great as differences between the soybean and the cowpea cross inoculation group.
2. Emphasis should be placed upon the isolation of strains of nodule bacteria best suited to the different varieties of soybeans and species of the cowpea group rather than attempting to place soybeans in the cowpea cross inoculation groups.
3. There is an indication that strains of soybean nodule bacteria isolated locally are more efficient than strains obtained from different climates.
4. The lime requirement of strains of soybean Rhizobia varies considerably.

LITERATURE CITED

1. ALWAY, F. J., and NESS, G. H. Inoculation of alfalfa on lime-deficient sandy soils; soil transfer vs. use of culture. Minn. Agr. Exp. Sta. Tech. Bul. 46. 1927.
2. BALDWIN, I. L., and HOFER, A. W. Variations in infective power among strains of Rhizobia. Jour. Bact., 23:66–67. (Abstract.) 1932.
3. CARROLL, W. R. A study of Rhizobium species in relation to nodule formation on the roots of Florida legumes. I. Soil Science, 37:117–135; II, Ibid: 227–241. 1934.
4. FRED, E. B., BALDWIN, I. L., and McCOY, E. Root nodule bacteria and leguminous plants. Univ. Wis. Studies in Sci., 5. 1932.
5. LEONARD, L. T. Nodule production kinship between the soybean and the cowpea. Soil Science, 15:277–283. 1923.
6. McCALLA, T. M. Behavior of legume bacteria (Rhizobium) in relation to exchangeable calcium and hydrogen ion concentration of the colloidal fraction of the soil. Mo. Agr. Exp. Sta. Res. Bul. 256. 1937.

7. MORSE, W. J. Note following Voores' paper (14). Jour. Amer. Soc. Agron., 7: 140. 1915.
8. ORCUTT, FRED S., and FRED, E. B. Light intensity as an inhibiting factor in the fixation of atmospheric nitrogen by Manchu soybeans. Jour. Amer. Soc. Agron., 27:550–558. 1935.
9. REED, J. J., and BALDWIN, I. L. Study factors affecting nodule formation in legumes. Wis. Agr. Exp. Sta. Bul. 438:147–148. 1937.
10. SEARS, O. H., and CARROLL, W. R. Cross inoculation studies with cowpea and soybean nodule bacteria. Soil Science, 24:413–419. 1927.
11. UMBREIT, WAYNE W., and FRED, E. B. The comparative efficiency of free and combined nitrogen for the nutrition of the soybean. Jour. Amer. Soc. Agron., 28:548–555. 1936.
12. WALKER, R. H. Physiological studies on the nitrogen fixing bacteria of the genus Rhizobium. Iowa Agr. Exp. Sta. Res. Bul. 113. 1928.
13. WILSON, P. W. The carbohydrate nitrogen relation in symbiotic nitrogen fixation. Wis. Agr. Exp. Sta. Res. Bul. 129. 1935.
14. VOORES, J. H. Variation in soybean inoculation. Jour. Amer. Soc. Agron. 7: 139–140. 1915.

"WEAK NECK" IN SORGHUM[1]

A. F. SWANSON[2]

DWARF varieties of grain sorghum adapted to combine harvesting have become very popular within the past eight years in regions where the crop is extensively grown. Varieties suited for this purpose must possess strong stalks and peduncles to prevent the heads from breaking over, because the crop often has to stand in the field until late fall in order to dry sufficiently for satisfactory combining and safe storage.

One of the difficulties experienced in selecting dwarf grain sorghums adapted to combine harvesting has been to find varieties with peduncles strong enough to maintain heads in an upright position. The breaking over of heads has been assumed by most sorghum workers to be due to the combined effects of wind, moisture, and gravity, accentuated by a greater leverage in varieties having long peduncles. It has also been thought that the translocation of more carbohydrates from the stalks into the heads of certain dry-stalked types might be a differentiating factor in decreasing resistance to lodging.

Although all of the above suggested factors may be operative, the chief factor influencing the percentage of broken over heads is now believed to be due to a specific malady in the peduncles. Whether the causal factor is an organism or a non-parasitic breakdown of the tissues remains to be determined. This apparent diseased condition seems to interfere with the translocation of organic material to the grain as evidenced by the poorly filled heads associated with weakened peduncles. When the weakened plants are subjected to the elements, many of the heads are likely to be broken over. This condition was very apparent at Hays, Kans., in the fall of 1937 when the examination of hundreds of individual plants showed that weak peduncles were nearly always associated with badly disintegrated tissues.

Many data have been published on broken and weak corn stalks, but these may be related only indirectly to the problem here discussed. Pammel, King, and Seal[3] in 1916 described a Fusarium disease of certain sorghum varieties as follows:

"When the Fusarium attacks sorghum, the canes break at the joints, sometimes beginning at the first joint; more frequently most of the joints are attacked. These readily break off. The roots are

[1]Results of investigation conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans., at the Fort Hays Branch Experiment Station, Hays Kans. Contribution No. 26, Fort Hays Branch Experiment Station.

The term "weak neck" was suggested by Prof. L. E. Melchers, Botany Department, Kansas State College of Agriculture and Applied Science, as descriptive of the diseased condition associated with broken peduncle and lodged heads in sorghum. Acknowledgment is gratefully made to Prof. L. E. Melchers and Dr. J. H. Parker for assistance in preparing this paper. Received for publication May 12, 1938.

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[3]PAMMEL, L. H., KING, D. M., and SEAL, J. L. Studies on a Fusarium Disease of corn and sorghum. Iowa Agr. Exp. Sta. Res. Bul. 33, 1916.

apparently not so seriously affected as in corn, as the plants are removed with difficulty from the ground. . . . We found in many cases that the plants affected are enfeebled by the disease and that the heads are small and not fully filled.

"The diseased heads show the fungus in the seed. Where the fungus occurs at the nodes the spores are found in great abundance on the surface of the stalk. The mass is whitish with a slight purplish tinge. The interior of the cane is disintegrated and purplish or brownish in color, with an abundance of the mycelium. The leaf sheaths give sufficient protection from drying out so that spores are produced there in great numbers. There is little decay beyond the nodes, most of the injury being confined to within half an inch of the node."

Some of the symptoms noted by these Iowa workers were apparent in the sorghum plants examined at Hays. The chief difference at Hays is that the disintegration of the tissue was confined almost entirely to the peduncle.

SYMPTOMS OF "WEAK NECK" OF SORGHUM

One of the symptoms of "weak neck" of sorghum is the disintegration of the tissues of the peduncle, associated with and indicated by a blackened or gray discoloration. This discoloration may be found in different degrees of intensity throughout the entire length of the peduncle, or in localized areas. The most vulnerable point of injury is at the junction of the peduncle and upper node of the stalk. In the more severe cases the affected areas may extend downward into the first or second internode. Sometimes the tissue disintegration at the base of the head is so extensive that the head will break off readily with the lightest mechanical shock. More commonly the disintegration is only slight and localized between the extremities of the peduncle. This generally causes little damage.

A second symptom is the large proportion of heads broken over where the peduncle joins the upper node of the stalk (Fig. 1). The tissues where the head is broken over are always badly disintegrated.

A third symptom is the presence of poorly developed, scrawny heads containing light-weight, lusterless seed. This is especially noticeable when a plant is affected early in its development. The symptoms are more marked in the earlier planted sorghums than in late plantings and more severe in main stalks than in tillers. Susceptible strains grown in the greenhouse at Hays during the winter of 1937–38 gave poorly developed plants with a high percentage of sterility, indicating that "weak neck" may be seed-borne. On the other hand, selections from varieties known to be resistant to the malady grew in the greenhouse with normal vigor.

Sorghum "weak neck" is frequently associated with the presence of aphids and more or less disintegration of the peduncle has been observed where aphids are abundant in the top sheaths. The reddening of the leaves and peduncle also seems to indicate that the plant tissue has been punctured. Whether or not aphids act as a vector of bacterial or fungus infection has not been determined.

FIG. 1.—"Weak neck," a sorghum disease which weakens the peduncle and causes the head to break over.

It has been observed that in certain varieties that appear to be susceptible to the disease, complete breaking-over does not necessarily follow unless aggravated by high wind and rain. Where the peduncle has reached the more acute stages of disintegration, a light jar of a standing sorghum head will break it over. The peduncle of a healthy sorghum plant ripens with a bright golden color and is capable of withstanding heavy blows or high winds for a considerable period after the grain is fully ripe. Breaks in a healthy peduncle tend to be clean rather than ragged and disintegrated. If a diseased peduncle is split with a knife, the darkened pit of the peduncle, as well as the gray discoloration of the cortical tissues, is evident.

INHERITANCE OF "WEAK NECK"

All true sorgos appear to be highly resistant to "weak neck", and of the grain sorghums, strains of Blackhull kafir and a new variety known as Club are among the most resistant. Milo seemingly is susceptible to "weak neck," but because of the consequent reduced leverage of short peduncles, the breaking over of the heads is rather infrequent; consequently, the malady may be present to a greater degree in milo than is likely to be recognized.

Hybrids between milo and kafir, and particularly those with long peduncles, appear to be especially susceptible. Observations of hundreds of plants in the hybrids of Club × Day and Wheatland Backcross × Club, Day, and Colby milo indicated high susceptibility. All of these sorghums are derived from crosses in which Dwarf yellow milo was one of the parents. It was estimated that 73% of all the plants in 98 late-generation progeny rows of the Club × Day cross in the early planting and 53% in a later planting were diseased. Other observations have shown that the disease is more prevalent in early-planted than in late-planted sorghums, although certain strains have shown an opposite reaction. In the Club × Day progenies the yellow-seeded segregates as a rule showed much higher susceptibility than did the white-seeded segregates that resembled the Club parent. A hopeful view of the situation is gleaned from the fact that occasionally immune plants were found in susceptible lines. Entire rows also were found with low susceptibility but nearly always among the white-seeded Club-like segregates.

Almost complete resistance to "weak neck" was noted in the F_3 progenies of the cross Leoti Red sorgo × Club. A number of dwarf plants with grain-producing possibilities occurred in this cross. Aphids were not abundant on plants of this cross. Since both the Club and Leoti Red have given evidence of resistance when used as parents in crosses, there is hope that "weak neck" can be controlled by plant breeding methods.

Wheatland, a grain sorghum well suited to combine harvesting, was found to be relatively resistant to weak neck. This is probably a factor accounting for the resistance to lodging of this variety, and for its consequent popularity.

"WEAK NECK" NOT ASSOCIATED WITH PYTHIUM ROOT ROT IN SORGHUM

Pythium root rot[4], attacks the roots and crowns of certain varieties of sorghum, causing early death in severe cases. Milo and most milo derivatives are highly susceptible to this disease. All roots and crowns of plants affected with "weak neck" which have been examined were found to be clean and healthy and showed no symptoms of Pythium root rot. Certain selections known to be resistant to Pythium root rot were among those also resistant to the "weak neck" disease.

[4]Bowman, D. H., Martin, J. H., Melchers, L. E., and Parker, John H. Inheritance of resistance to pythium root rot in sorghum. Jour. Agr. Res., 55:105–115. 1937.

Elliott, Charlotte, Melchers, L. E., Lefebvre, C. L., and Wagner, F. A. Pythium root rot of milo. Jour. Agr. Res., 54:797–834. 1937.

"WEAK NECK" NOT YET A FARM PROBLEM

While weak peduncles and lodged heads often have been seen in the plant breeding nurseries at Hays and at other stations, the presence of this diseased condition has not been observed generally on farms. The reason for this may be that many of the varieties of sorghum grown on farms have shown high resistance to "weak neck." Wheatland, the leading sorghum grown for combine harvesting, is relatively resistant to "weak neck". However, the distribution of dwarf types of sorghum suited to combine harvesting but susceptible to "weak neck" may lead to a serious farm problem unless plant breeders take the necessary precautions to avert such a condition.

SUMMARY

Dwarf varieties of sorghum adapted to combine harvesting must have sturdy stalks and peduncles to prevent the heads from breaking over.

Many selections, particularly from milo-kafir crosses, have shown high tendency for the production of weak peduncles. The term "weak neck" has been designated to describe this condition. The cause of the malady has not yet been determined.

The affected tissues become disintegrated and so weakened that the heads break over. The break occurs most frequently at the base of the peduncle.

The sorgos and strains of Blackhull kafir show high resistance to "weak neck," while the milo and milo derivatives having milo characteristics often show high susceptibility.

"Weak neck" is not yet of wide occurrence on farms because the varieties grown are for the most part resistant to the disease. The distribution of varieties susceptible to "weak neck," however, will increase the prevalence of the disease.

Late planting on a well-prepared seedbed tends to reduce the prevalence of "weak neck" in susceptible varieties. More complete control may be expected from plant breeding methods.

HYDROCYANIC ACID CONTENT OF DIFFERENT PARTS OF THE SORGHUM PLANT[1]

J. H. MARTIN, JAMES F. COUCH, AND REINHOLD R. BRIESE[2]

THE highly toxic nature of hydrocyanic acid liberated from nitrile-glucosides in certain plants, including sorghum (*Sorghum vulgare* Pers.), and the extensive outbreaks of poisoning among domestic animals resulting from grazing on these plants, are of extreme interest both to animal toxicologists and livestock owners. Since poisoning may depend upon the part of these plants eaten by animals, as well as upon numerous other factors, it is important to know how the potential hydrocyanic acid varies in different parts of the plant. This distribution of hydrocyanic acid is of interest also to agronomists and plant physiologists. The origin, rôle, and fate of these nitrile-glucosides in the plant economy are not clearly understood, but they probably are important intermediate compounds in the process by which inorganic nitrogen is converted into protein. Data concerning the relative proportions of the nitrile-glucosides in the various tissues should be of considerable value in solving problems of plant metabolism.

REVIEW OF LITERATURE

Several investigators have published data on the relative quantities of hydrocyanic acid obtained from leaves, stalks, roots, heads, and other tissues of sorghum and other plants. These data show that in different genera there is a variation in the utilization by the plant of hydrocyanic acid or the glucosides that yield it on hydrolysis. The cyanogenetic compounds appear to be synthesized in the leaves and, in some genera, they are translocated to other parts of the plant, including the bark, pith, roots, and seeds.

Willaman and West (12)[3] reported that stalks of feterita sorghum were higher in HCN than the leaves before the plants were 47 days old, after which they were lower, and the stalks contained almost no HCN after 67 days. In Orange sorgo the stalks were higher than the leaves in HCN at the age of 25 days, but the HCN had disappeared from the stalks at the age of 43 days. The same authors later reported (13) that the distribution of hydrocyanic acid in the leaves and stalks was variable in Early Amber sorgo and another variety designated as "Southern cane." Specimens of these varieties grown in Utah contained more hydrocyanic acid in the stalks than in the leaves of young plants but more in the leaves than in the stalks of older plants.

Ghosh (5), working in India, reported 1.5 to 7 times as much hydrocyanic acid in leaves of sorghum (variety and age of plant not stated) as in the stalks.

Swanson (8) found that the leaves of Sudan grass contained much more potential hydrocyanic acid than the stems. From three samples he obtained 33.5, 16.5, and 33 mg of HCN per hundred grams from the leaves and 2.5 mg, traces, and none from the corresponding stems.

[1]Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, and the Pathological Division, Bureau of Animal Industry, U. S. Dept. of Agriculture. Received for publication May 13, 1938.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, and Chemist and Junior Chemist, Pathological Division, Bureau of Animal Industry, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 733.

Pinckney (7) found more hydrocyanic acid in the leaves than in the stems of an unspecified variety of sorghum.

Acharya (1) in India reported the following mg of hydrocyanic acid per 100 grams of tissue from parts of stunted sorghum plants: Leaves, 13.8; stems, 4.9; and roots, 10.0. He found more HCN in the branches than in the main stem.

Similar relationships have been reported for other cyanogenetic plants. Treub (9) stated that Greshoff found in dried material of *Pangium edule* the following quantities of hydrocyanic acid per 100 grams of tissue: Stems, 1,098 mg; leaves, 679 mg; and petioles, 357 mg; and "large quantities" in the roots. Van Itallie (10) found much more hydrocyanic acid in the leaves than in the stems of *Thalictrum aquilegifolium.* Guignard (6) grew eight varieties of lima beans in his garden at Paris and determined the hydrocyanic acid in the leaves and seeds of each variety. He found that in three varieties the leaves contained two to three times as much as the seeds but in the other five varieties the relationship was reversed and the seeds yielded two to six times as much as the leaves. Guignard recognized that the plants were grown outside their natural habitat and that these relationships may be different in plants grown under conditions more suitable to their development.

The distribution of HCN in certain other grasses also has been investigated. Alsberg and Black (2) found the following quantities of HCN in dried *Panicularia nervata:* Seeds, 32.5 mg per 100 grams of tissue; roots, 32.5 mg; stems, 41.6 mg; and in the entire plant 55.5 mg HCN per 100 grams of tissue. Viehoever, Johns, and Alsberg (11) reported hydrocyanic acid in *Tridens flavus* as follows: Inflorescence stripped of flowers, 3.7 mg; stems, 3 mg; green leaves, 1.7 mg per 100 grams of tissue; dead yellow leaves, none; roots, trace.

Beath, Draize, and Eppson (3) found that more hydrocyanic acid was developed from leaves than from seeds, seed stalks, and flower stalks of arrow grass, the total hydrocyanic acid being distributed as follows: Leaves, 65%; stems, 20%; and seeds, 15%.

While most of the figures given above are undoubtedly in error because the methods of analysis used are now known to be inaccurate and because of unrecognized sources of loss during the actual analyses, they may still be accepted as having considerable value for comparing relative quantities of hydrocyanic acid obtained from different parts of the same specimens of plants analyzed under the same conditions. More detailed information is desirable, however, especially concerning a larger number of varieties and concerning plants grown under different conditions and in different seasons.

MATERIAL AND METHODS

As a part of a general study of the effect of variety and environment upon HCN development in sorghums, a number of analyses were made during the summer of 1936 to obtain further information upon the HCN content of various parts of the sorghum plant. Samples of fresh plants were collected at Arlington Farm, Arlington, Va., near Washington, D. C., and were analyzed immediately for HCN content. A larger number of samples was collected in the Great Plains area at three field stations of the Division of Dry Land Agriculture, Bureau of Plant Industry, through the courtesy of B. F. Barnes, Dalhart, Tex., D. R. Burnham, Tucumcari, N. Mex., and J. J. Curtis, Akron, Colo., who grew the crop, took the plant samples, weighed 100-gram samples of the green tissues immediately, placed them in pint fruit jars, and then filled the jars with 15% alcohol

to preserve the material. The plants when sampled were two months old or older and the main stalks had reached at least the boot stage. The samples were shipped to the laboratory at Washington, D. C., and analyzed as soon as possible after arrival, the periods between collection and analysis being 7 to 14 days.

It has been shown by Briese and Couch (4) that 15% alcohol will preserve green sorghum samples for two to three weeks sufficiently well for ordinary analytical purposes. However, it is now known that this solution cannot be depended upon to develop and preserve the entire amount of hydrocyanic acid which a plant is capable of producing. The determinations from the preserved samples in the 1936 series may be, and probably are, somewhat lower than the actual potential quantities in the plants. This possible discrepancy would require that they be discarded were it not for the fact that they have considerable value for comparative purposes.

In 1937, similar experiments were made with fresh sorghum grown at the same stations. The technic used was the same as in 1936 except that the samples were preserved in mercuric chloride solution containing 1 gram of the salt per 100 grams of sample. The samples were allowed to stand in the laboratory until one to two months had elapsed after collection to allow cyanogenesis to become practically complete, and were then analyzed. Experience with this method has shown that for periods longer than two months the full quantity of HCN can be retained in the samples and that frequently the quantities obtained are higher, and the results therefore more representative, than those obtained by immediate analysis without the use of preservatives.

The samples were analyzed in accordance with Denigès modification of the Liebig titration method described, together with the method of preservation, by Briese and Couch (4). The data show the HCN content on a green weight basis because moisture determinations were not made on all samples in 1936.

EXPERIMENTAL RESULTS

Table 1 contains the data obtained in 1936 from plants grown at Tucumcari, N. Mex., and Akron, Colo., showing comparisons of HCN in leaves, stems, heads, sheaths, and suckers. The duplicate specimens of Atlas, Kansas Orange, and Black Amber sorgos of the September 5 collection at Akron were from portions of the plats where moisture conditions were different. The first set of samples listed for each variety was from plants that were stunted and badly wilted, while the plants in the second set were nearly normal in growth and only slightly wilted. The data show the highest HCN content in the leaves with only small quantities in the sheaths, stems, and heads. Suckers (tillers) contained more HCN than the main stalks.

The detailed distribution of HCN in the various parts of the sorghum plant was determined by an experiment in which the heads, peduncles, sheaths, and individual leaves and internodes were analyzed separately. Plants of the variety Leoti Red sorgo planted on June 4, and 13 weeks old, were collected at Dalhart, Tex., on September 4, 1936. The plants were at that time 27 inches high, had headed, and were severely wilted. A bundle of 50 plants of approximately the same size was gathered about 1 p.m. and taken to the laboratory on the grounds where the plants were stripped of their leaves and sheaths and the stalks cut into sections through each node. Duplicate samples

TABLE 1.—*Hydrocyanic acid content of different parts of sorghum plants grown at Tucumcari, N. Mex., or Akron, Colo., in 1936.*

Variety	Date collected	Date analyzed	HCN in mg per 100 grams of green tissue						
			Leaves	Leaves and stems	Leaves and heads	Sheaths	Stems	Suckers	Heads
Tucumcari, N. Mex.									
Dawn kafir	Aug. 18	Sept. 1	—	17.8	—	—	4.9	—	—
Dwarf hegari	Aug. 18	Sept. 1	—	40.0	—	—	11.9	—	—
Sumac sorgo	Aug. 18	Sept. 1	—	45.9	—	—	4.3	—	—
Atlas sorgo	Aug. 18	Sept. 1	—	41.0	—	—	2.7	—	—
Honey sorgo	Aug. 18	Sept. 1	—	21.1	—	—	3.2	—	—
Kansas Orange sorgo	Aug. 18	Sept. 1	—	14.0	—	—	8.6	—	—
Feterita	Aug. 25	Sept. 3	—	43.5	—	—	6.2	—	—
Dwarf Yellow milo	Aug. 25	Sept. 3	—	31.9	—	—	3.5	—	—
Dawn kafir	Aug. 25	Sept. 3	—	—	—	—	1.1	13.8	—
Texas Blackhull kafir	Aug. 25	Sept. 3	—	—	20.0	—	3.2	—	—
Dwarf hegari	Aug. 25	Sept. 4	40.0	—	—	—	8.6	—	—
Sumac sorgo	Aug. 25	Sept. 4	37.0	—	—	—	3.2	—	—
Atlas sorgo	Aug. 25	Sept. 4	—	13.3	—	—	1.6	—	—
Honey sorgo	Aug. 25	Sept. 4	21.6	—	—	—	1.6	—	—
Kansas Orange sorgo	Aug. 25	Sept. 4	25.4	—	—	—	4.1	—	—
Acme broomcorn	Aug. 25	Sept. 4	—	—	—	—	3.5	12.4	—
Akron, Colo.									
Sudan grass	Aug. 25	Sept. 4	26.2	—	—	—	5.7	—	—
Sudan grass (tillers)	Aug. 25	Sept. 4	25.4	—	—	—	5.2	—	—
Atlas sorgo	Sept. 5	Sept. 17	27.0	—	—	5.7	2.7	—	7.2
Atlas sorgo	Sept. 5	Sept. 17	29.7	—	—	5.4	3.2	—	8.4
Kansas Orange sorgo	Sept. 5	Sept. 17	50.8	—	—	7.0	4.9	—	8.1
Kansas Orange sorgo	Sept. 5	Sept. 17	52.4	—	—	6.5	—	—	7.6
Black Amber sorgo	Sept. 5	Sept. 17	24.1	—	—	3.2	—	—	2.7
Black Amber sorgo	Sept. 5	Sept. 17	22.7	—	—	3.0	3.2	—	3.0

were then weighed, representing composites of the leaves in each position from the top leaf down to the fifth leaf. The weighing was completed by 2:30 p.m. The number of living leaves on the stalks varied and the lower leaves were so small that the sixth leaves were composited with the seventh and any lower green leaves. Dead leaves were discarded. The internodes from corresponding positions on the different stalks likewise were composited. The second and third internodes from the top were composited because of their short length. On the following day specimens of this variety were collected from the same plat and the whole plant was sampled for analysis. The samples were preserved in 15% alcohol, shipped to Washington, and analyzed on September 11. The results are presented in Table 2 and diagramatically in Fig. 1.

TABLE 2.—*Hydrocyanic acid content in mg per 100 grams of green tissue of different parts of Leoti Red sorgo plants at Dalhart, Tex., in 1936, average of two samples.*

Part of plant	Hydrocyanic acid, mg	Part of plant	Hydrocyanic acid, mg
Leaf 1 (top)	18.6	Peduncle	3.9
Leaf 2	18.3	Internodes 2 and 3	4.6
Leaf 3	14.5	Internode 4	2.8
Leaf 4	12.8	Internode 5	1.7
Leaf 5	9.8	Internode 6	1.6
Leaf 6	7.3	Internode 7	2.9
Upper 3 sheaths	3.6	Internode 8	2.4
Fourth and 5th sheaths	2.8	Internode 9	1.6
Heads	2.1	Entire plant (following morning)	8.4

The figures obtained show the largest yield of HCN from the leaves and in general a progressive diminution in HCN content from the top of the plant to the bottom both in leaves and in stem internodes. The small amount of HCN that was recovered from the heads is to be attributed to the green stems, branches, and glumes included in the samples since the grain was not yet developed and mature grain itself is cyanide-free. Inasmuch as the upper leaves are younger than the lower, the figures indicate an accumulation of nitrile-glucoside in the more actively growing parts of the plant thus conforming with the common observation that the HCN content of sorghum plants decreases with age.

A similar set of samples was collected in 1937 at Tucumcari, N. Mex. On September 21 succulent plants of hegari, 42 inches high and headed, were selected at 2 to 4 p.m. and divided into leaves plus sheaths, peduncles, internodes, and heads. Short internodes near the base of the stalks were grouped together and composited. Table 3 presents the figures obtained for the HCN yielded by the plant sections.

The leaves again yielded considerably more HCN than the internodes, but the differences were more pronounced than in the former experiment. The ratio of leaf HCN to internode HCN ranged from

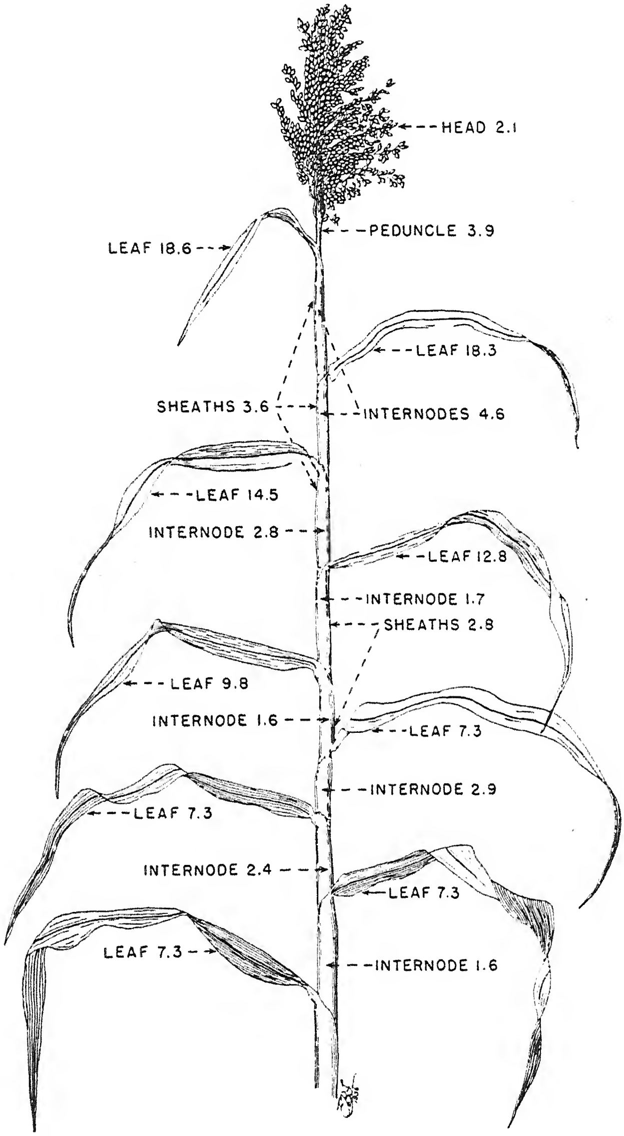

FIG. 1.—Sketch of a sorghum plant showing the HCN content in mg per 100 grams of green tissue of various plant parts. (Data from Table 2.)

10:1 to 25:1 as compared with 3:1 to 5:1 in the earlier experiment. Some of this higher HCN content as compared with the previous experiment may have been due to the improved method of preservation, but much of it is to be attributed to a varietal difference. However, the largest quantity of HCN was not yielded by the topmost

TABLE 3.—*Hydrocyanic acid content in mg per 100 grams of green tissue of different parts of hegari plants at Tucumcari, N. Mex., in 1937, average of two samples.*

Part of plant	Hydrocyanic acid, mg	Part of plant	Hydrocyanic acid, mg
Leaf 1 (top)	39.4	Peduncle	11.0
Leaf 2	47.3	Internode 2	4.6
Leaf 3	52.3	Internode 3	3.5
Leaf 4	56.0	Internode 4	3.0
Leaf 5	50.3	Internode 5	2.6
Leaf 6	46.7	Internode 6	2.1
Leaf 7	51.9	Internode 7	2.3
Leaf 8	51.5	Internodes 8 and 9	2.2
Leaf 9	48.1	Internodes 10 and 11	2.4
Leaf 10	42.9	Bottom internodes	1.5
Leaf 11	33.6	Whole plant	29.1
Leaf 12	27.5	Head	14.1
Leaf 13	19.0		

leaves, the maximum being obtained from the fourth leaf with a progressive increase from the first to the fourth leaf. In the internodes the HCN decreased progressively from the top to the bottom sections.

Samples of certain parts of Early Sumac sorgo plants were taken on two dates at the Akron station in 1937 and preserved in mercuric chloride. They were analyzed 2 and 2½ months after collection. The results are presented in Table 4. The ratio of the HCN content in a leaf to that of the comparable internode is 7:1 for the top and 19:1 for the bottom sections. Comparison of the figures for the whole leaves of the September 8 collection with those for the top and bottom leaves suggests that neither represents the maximum, but that intermediate leaves must have contained considerably more HCN than those analyzed.

TABLE 4.—*Hydrocyanic acid content of different parts of Early Sumac sorgo grown at Akron, Colo., 1937.*

Part of plant	Hydrocyanic acid content in mg per 100 grams of green tissue	
	Sampled Sept. 8	Sampled Sept. 25
Whole plant	—	9.2
Leaves	52.6	67.9
Top leaf	38.7	—
Bottom leaf	32.5	—
Peduncle	5.5	3.8
Top internode	5.5	—
Middle internode	1.7	—
Bottom internode	1.4	1.7
Heads	—	2.3

Further data were obtained from samples collected at Dalhart, Tex., in 1937 and preserved in mercuric chloride. The figures are presented in Table 5.

Hegari samples from plants 36 inches high and from suckers of the same plants 30 inches high gave a ratio of between 7 and 8 to 1 for

TABLE 5.—*Hydrocyanic acid content of different parts of sorghum plants grown at Dalhart, Tex., 1937.*

Date collected	Variety	Part of plant	Height of stalk, in.	Hydrocyanic acid, mg per 100 grams of green tissue
Sept. 2	Hegari	Leaves	36	48.5
2	Hegari	Stems, sheaths, and heads	36	6.5
2	Hegari	Sucker leaf blades	30	48.8
2	Hegari	Sucker stems, sheaths, and heads	30	6.5
Oct. 11	Hegari	Main stalk with head	38	3.8
11	Hegari	Main stalks without head	38	4.5
11	Hegari	Entire sucker	60	13.4
11	Feterita	Side branches, head immature	—	37.3
11	Feterita	Main stalk, head immature	60	5.6

the HCN contents of leaves as compared with mixed stalks, sheaths, and heads. The much higher content of a side branch as compared with the main stalk is indicated by the figures obtained from samples of feterita, collected on October 11. The immature branches yielded over 6 times as much HCN as the mature main stalks. The plants were 60 inches high and the branches 24 to 30 inches long, originating about half way up the stalk.

Experiments conducted with fresh plants collected at Arlington Farm and analyzed immediately showed similar differences between leaves and stalks. An additional experiment was conducted to determine the distribution of the glucoside in the various portions of the leaf itself. The results are presented in Table 6.

TABLE 6.—*Hydrocyanic acid content of parts of sorghum plants grown at Arlington, Va., in 1936.*

Variety	Part of plant	Hydrocyanic acid, mg per 100 grams of green tissue
Spur feterita	Leaves	26.5
Spur feterita	Pith	3.2
Hegari*	Leaves	19.7
Hegari*	Stems	2.2
Hegari†	Whole leaf	12.4
Hegari	Same leaf minus midrib	14.3
Hegari	Midrib	2.4
Hegari	Distal half of leaf	6.7
Hegari	Proximal half of leaf	16.2

*Grown in greenhouse, sampled Nov. 24.
†Field grown, sampled Oct. 1.

These figures show a ratio of 8:1 for Spur feterita and 9:1 for hegari for the relative HCN content of leaves and stems. In the case of the feterita stalks, the cortex which contained the chlorophyll was shaved from the stalk and the pith only was analyzed. The presence of HCN in this non-photosynthesizing tissue suggests either a slight translocation of the glucoside from the leaves or a diffusion of that substance from the green tissues into the interior of the stalk. The

difference in HCN content between the distal and proximal halves of the leaf, being 6.7 mg and 16.2 mg, respectively, in the two portions, indicates a great dissimilarity either in synthetic or in the storing capacity of the tissues. The distal portion is the older tissue. It is of interest that the mean of the figures found, 11.45, is very close to the figure found for the whole leaf, 12.4.

The results obtained in both years indicate that by the time the plants reach the boot stage the leaves contain the greater proportion of nitrile-glucoside and that the upper leaves contain more than those lower and nearer the ground. Data were obtained concerning 15 varieties, all of which showed the same general distribution of the glucoside between leaves and stalks. Four of these varieties were grown at two or more stations and the relationship between leaves and stems in HCN content was maintained.

In outbreaks of sorghum poisoning it often is observed that some of the animals in the herd die while others become sick and recover, and still others are unaffected. These erratic occurrences of poisoning when animals enter a sorghum field may be due in part to the large differences in hydrocyanic acid content between leaves and stalks and between young and older parts of the sorghum plant reported here. Animals that begin eating young leaves or branches might become poisoned within a few minutes, while those eating mostly heads or stalks would ingest only small quantities of HCN and at the same time would have the poisonous effects counteracted to some extent by the glucose and other carbohydrates in these parts.

It is recognized that individual differences in the animals as well as in the plants consumed, and environmental factors, also play a part in the frequency of sorghum poisoning.

SUMMARY

The hydrocyanic acid content of various parts of the sorghum plant was determined in material grown in Texas, New Mexico, Colorado, and Virginia in 1936 and 1937. The HCN content of sorghum leaves was 3 to 25 times that of the corresponding stalks of plants that had reached the boot stage. Heads and leaf sheaths were low in HCN. Upper (younger) leaves contained more HCN than lower (older) leaves. The proximal half of the leaf was higher in HCN than the distal (older) half. The HCN content of leaf blades was six times that of the midribs. The HCN content of stalk internodes decreased progressively downward, the lower (older) internodes containing only small quantities. Axillary (side) branches were much higher in HCN than the older main stalks and in most cases tillers (suckers) were higher in HCN than the older main stalks of the same plants.

LITERATURE CITED

1. Acharya, C. N. Investigations on the development of prussic acid in cholam (*Sorghum vulgare*). Indian Jour. Agr. Sci., 3:851–869. 1933.
2. Alsberg, C. L., and Black, O. F. Concerning the distribution of cyanogen in grasses, especially in the genera Panicularia or Glyceria and Tridens or Sieglingia. Jour. Biol. Chem., 21:601–609. 1915.

3. BEATH, O. A., DRAIZE, J. H., and EPPSON, H. F. Arrow grass—chemical and physiological considerations. Wyo. Agr. Exp. Sta. Bul. 193:1–36. 1933.
4. BRIESE, R. R., and COUCH, J. R. The preservation of cyanogenetic plants for analysis. Jour. Agr. Res., 57:81–107. 1938.
5. GHOSH, M. Notes on the hydrocyanic acid content of Jowar (*Andropogon sorghum*). Agr. Jour. India, 14:107–115. 1919.
6. GUIGNARD, L. Sur les quantites d'acide cyanhydrique fournies par le *Phaseolus lunatus* L. cultive sous le climat de Paris. Bul. Sci. Pharmacol., 9:565–569. 1907.
7. PINCKNEY, R. M. Effect of nitrate applications upon the hydrocyanic acid content of sorghum. Jour. Agr. Res., 27:717–723. 1924.
8. SWANSON, C. O. Hydrocyanic acid in Sudan grass. Jour. Agr. Res., 22:125–138. 1921.
9. TREUB, M. Sur la localisation, le transport et le rôle de l'acide cyanhydrique dans le *Pangium edule* Reinw. Ann. Jard. Bot. Buitenzorg., 13:1–96. 1896.
10. VAN ITALLIE, L. Sur l'existence dans le *Thalictrum aquilegifolium* d'un compose fournissant de l'acide cyanhydrique. Jour. Pharm. et Chim., 22:337–338. 1905.
11. VIEHOEVER, A., JOHNS, C. O., and ALSBERG, C. L. Cyanogenesis in plants. Studies on *Tridens flavus* (tall red top). Jour. Biol. Chem., 25:141–150. 1919.
12. WILLAMAN, J. J., and WEST, R. M. Notes on the hydrocyanic-acid content of sorghum. Jour. Agr. Res., 4:179–185. 1915.
13. ————. Effect of climatic factors on the hydrocyanic-acid content of sorghum. Jour. Agr. Res., 6:261–272. 1916.

THE EFFECT OF FERTILIZER ON THE LENGTH OF WINTER WHEAT HEADS[1]

R. L. Cook and W. D. Baten[2]

A SURVEY of the results from several experiment stations reveals the fact that wheat is more responsive than most other farm crops to applications of commercial fertilizer. The reasons for this have been set forth by agronomists in various sections of the country. Thatcher (8)[3] found that phosphorus and potassium increased the test weight per bushel and that nitrogen applied in combination with the other elements caused a further increase, but that nitrogen alone or in combination with either phosphorus or potassium caused a decrease in test weight. Bayfield (1) likewise obtained an increase in test weight per bushel as a result of fertilizer application. Millar (4) reported that phosphoric acid fertilizers resulted in plumper kernels of a higher market value.

Winter wheat yields are often depressed by serious winter injury. The fact that fertilizer, properly used, is effective in preventing winter killing of wheat has been observed by Grantham and Millar (3) and by Cook and Millar (2).

Thatcher (8) found that sodium nitrate applied early in the spring increased the number of tillers per plant. Richardson and Fricke (6) found that nitrogen increased the number of head-bearing tillers and also the number of heads per plant at harvest time. On seven experimental fields in central Kansas, Parsons (5) found that nitrogen neither increased the number of heads nor the yields, but that superphosphate fertilizer resulted in greater yields and that the difference in yield was almost all accounted for by the increase in tillering. He reported a slight tendency toward larger heads, especially on one field of inferior soil.

It is commonly believed that increased length of head is a source of greater yields of wheat due to fertilizer application. Grantham and Millar (3) working on sandy soils found the heads of fertilized wheat to be longer than those of unfertilized wheat. Richardson and Gurney (7) showed that ammonium sulfate resulted in vigorous tillering and slightly longer heads.

It is the purpose of this paper to show the effect of fertilizers on the length of wheat heads grown on three silt loam soils during a period of three years and to show how many heads constitute a sample representative of the entire population. A comparison of statistical methods is also included.

SOURCE OF HEADS MEASURED

The heads used in the 1935 measurements were obtained from the Ferden experimental field in Saginaw County. The wheat was grown

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[3]Figures in parenthesis refer to "Literature Cited," p. 742.

in rotation with alfalfa, corn, and oats and the fertilizer treatments were in triplicate. Each bundle or group of heads measured was obtained from 3 rods of row, 1 rod taken at random from each of the three replicates.

The 1936 measurements were taken on heads from the Dilman experimental field in Tuscola County. Each group of heads was obtained from 120 feet of row in each plat.

The 1937 measurements were made on heads from the Drumheller farm in Clinton County. Each group of heads came from 1 rod of row. The field was not an established experimental field, but was simply a farm field where the unfertilized strip was the result of failure of the drill to apply fertilizer.

RESULTS FOR 1935

To facilitate the handling of so many measurements, the data were grouped into 0.3-cm classes. The 1935 frequency distributions for six different fertilizer treatments and an unfertilized control are shown in Table 1. The mean length of head for each treatment, with its standard deviation, is also included. The data show that the unfertilized wheat produced longer heads than did the fertilized wheat.

TABLE 1.—*The effect of fertilizers on the length of winter wheat heads grown on the Ferden farm in 1935.*

Classes, cm	Frequencies with different fertilizers							Complete frequency distribution
	0-0-0 1	0-16-0 2	0-16-8 3	4-12-4 4	4-16-0 5	4-16-4 6	4-16-8 7	
1.35-1.65	0	0	0	0	0	0	2	2
1.65-1.95	0	2	0	0	1	1	4	8
1.95-2.25	3	6	1	2	3	2	3	20
2.25-2.55	5	5	3	5	6	6	8	38
2.55-2.85	4	10	19	12	14	5	9	73
2.85-3.15	11	21	15	19	17	15	24	122
3.15-3.45	12	37	24	29	32	21	21	176
3.45-3.75	26	46	38	51	32	49	33	275
3.75-4.05	39	54	92	82	68	68	87	490
4.05-4.35	51	89	100	97	95	97	86	615
4.35-4.65	69	119	112	127	123	121	143	814
4.65-4.95	65	130	123	112	122	126	174	852
4.95-5.25	100	151	137	145	141	158	154	986
5.25-5.55	118	147	139	171	140	139	143	997
5.55-5.85	79	143	102	121	125	146	119	835
5.85-6.15	76	71	80	93	106	100	82	608
6.15-6.45	50	60	43	42	50	61	41	347
6.45-6.75	41	27	27	28	43	18	21	205
6.75-7.05	19	11	8	13	25	10	6	92
7.05-7.35	18	5	0	4	5	0	3	35
7.35-7.65	3	3	0	1	1	3	0	11
7.65-7.95	1	2	0	1	0	0	1	5
7.95-8.25	2	0	0	0	0	0	0	2
No. stalks	792	1,139	1,063	1,155	1,149	1,146	1,164	7,608
Mean	5.215	4.970	4.901	4.948	5.025	5.000	4.893	4.984
S. D. of mean	.0329	.0275	.084	.073	.0273	.0274	.0272	——

The data presented in Table 1 were analyzed to determine whether the differences between the mean lengths of heads were significant. As shown by the analysis of variance in Table 2, a between treatment means variance of 10.559 compared to a within treatment variance of 0.860 (F equals 12.3) shows that a significant difference exists between at least two of the means.

TABLE 2.—*Analysis of variance for 1935 Ferden wheat head measurements.*

Source of variation	Degrees of freedom	Sum of squares	Variance	Estimate of S. D.
Total	7,607	6601.77	.868	—
Between treatment means	6	63.29	10.559	—
Within treatments	7,601	6538.48	.860	.927

F = 12.3 (significant).

Since the data in Table 1 are grouped data, Shepherd's corrections[4] were made on the "sum of squares" to remove errors due to grouping. The correction is made only for the total "sum of squares". The "sum of squares" for treatments needs no correction unless the means of treatments are grouped into classes. As a rule there are not enough treatment means to group into classes. The analysis of variance after these corrections for grouping were made is shown in Table 3. The F value of 12.4 is practically the same as the F obtained without Shepherd's corrections. Nothing was gained in this case by using the corrections for grouping.

TABLE 3.—*Analysis of variance for 1935 Ferden wheat head measurements after corrections for grouping were made on the sum of squares.*

Source of variation	Degrees of freedom	Sum of squares	Variance	Estimate of S. D.
Total	7,607	6544.713	.8604	—
Between treatment means	6	63.292	10.5487	—
Within treatments	7,601	6481.421	.8527	.923

F = 12.4 (significant).

Using 0.923 as standard deviation with 7,601 degrees of freedom, tests were made for significance between the means shown in Table 1. The difference between the various means, with the standard deviation of the differences and the t values with indications of significance are shown in Table 4. The data show that the mean length of the unfertilized heads was significantly (1% point) greater than the mean length of the heads from any of the fertilized areas.

Certain fertilizers also resulted in longer heads than did other fertilizers. The heads from the areas treated with 4–16–0 were significantly longer than those from areas treated with 4–16–8, 0–16–8, or 4–12–4. Also, 4–16–4 fertilizer produced longer heads than did 4–16–8 or 0–16–8. The heads from plats treated with 0–16–0 were longer than those

[4]Shepherd's correction for the total "sum of squares" is $\left[\Sigma X^2 - \frac{(\Sigma X)^2}{N} - \frac{N}{12}\right] C^2$, where C equals class width and N is the number of measurements.

TABLE 4.—*The differences between the means, with the standard deviation of the differences and t values, of the 1935 Ferden wheat head measurements.*

Description	Differences	S. D. of differences	t
M_1–M_7	.33	.043	7.67**
M_1–M_3	.32	.043	7.44**
M_1–M_4	.27	.043	6.28**
M_1–M_2	.25	.043	5.81**
M_1–M_6	.22	.043	5.12**
M_1–M_5	.19	.043	4.42**
M_5–M_7	.14	.039	3.59**
M_5–M_3	.13	.039	3.33**
M_5–M_4	.08	.039	2.05*
M_6–M_7	.11	.039	2.82**
M_6–M_3	.10	.039	2.56*
M_2–M_7	.08	.039	2.05*

*Significance based on 5% point.
**Significance based on 1% point.

treated with 4–16–8. There seems to be some indication from these results that nitrogen tended to increase the length of head while potash had a tendency to shorten the heads. More measurements would be necessary, however, before these conclusions could be definitely drawn.

It is interesting to note that there were 792 heads in the bundle from the unfertilized plats as compared with 1,063 in the bundle from the plats treated with 0–16–8 and an average of 1,087 heads per bundle for all plats. The percentage $\frac{792}{7,608}$ is significantly smaller than the percentage $\frac{1,087}{7,608}$, hence, the number of heads in the bundle from the control is significantly smaller than the number of heads in the bundles from the treated areas. This increase in number of heads per unit area is due to better germination, the effect of fertilizer in stimulating tillering, or in the prevention of winter killing. All of these factors may have been effective.

RESULTS FOR 1936

The 1936 measurements were confined to heads from one fertilizer treatment and from control areas. As in 1935, the data were grouped into 0.3-cm classes. There were a total of 1,001 heads from 120 feet of row in the unfertilized area and 1,659 heads from an equal area in the fertilized area. Only 998 of the fertilized heads were measured. Since the frequency distributions resemble those obtained in 1935, they are not presented, but the means with their standard deviations are presented in Table 5. The value of t shows that the heads from the plats treated with 4–16–4 were significantly longer than those from the unfertilized area.

These data are in direct conflict with those obtained from the 1935 measurements, but a plausible explanation is available. There were

TABLE 5.—*The effect of fertilizer on the length of winter wheat heads grown on the Dilman farm in 1936.*

Treatment	Means	S. D.
0–16–4	7.40 cm	.03 cm
0–0–0	6.81 cm	.04 cm

$$t = \frac{\text{Difference of means}}{\sigma \text{ difference of means}} = 11.4 \text{ (significant).}$$

16.0 heads per foot of row on the unfertilized area in 1935 as compared to 8.3 heads in 1936. The average number of heads per foot of fertilized row in 1935 was 22.9 as compared to 13.8 in 1936. With such a thick stand as was the case in 1935 the effect of fertilizer in increasing the number of heads from 16.0 to 22.9 per foot of row resulted in sufficient crowding actually to shorten the heads. On the other hand, with the relatively thin stand of 1936, an increase in the number of heads from 8.3 to 13.8 per foot did not result in sufficient crowding to decrease the length of head, but rather the fertilizer was effective in producing a longer head.

As already mentioned, Grantham and Millar (3) reported data which showed a larger head as the result of fertilizer application. Their results were obtained on wheat having only 6.6 heads per foot of row on the unfertilized area and 14.2 heads per foot of row on the fertilized area. In other words, where the stand of wheat was relatively thin on the unfertilized land, application of the proper fertilizer resulted in longer heads, but where the stand was thick on the unfertilized land the increase in the number of heads, due to tillering, better germination, or less winter killing, caused sufficient crowding actually to shorten the heads.

RESULTS FOR 1937

The 1937 measurements were made on wheat from a field fertilized with 2–12–6 fertilizer and from an unfertilized strip in the same field. The heads from 1 rod of row were measured in each case. There were 61 heads from the unfertilized row and 202 from the fertilized row. The data presented in Table 6 show the mean lengths of heads and their standard deviations. A t value of 0.2365 shows that there is no significant difference between the two means. It was believed that the lack of significance between the means was due to the small number of measurements. Calculations on the 1935 data relative to the number of measurements necessary for a true sample showed this to be true. A discussion of these calculations follows.

TABLE 6.—*The effect of fertilizer on the length of winter wheat heads grown on the Drumheller farm in 1937.*

Treatment	Means	S. D.
2–12–6	7.17	.09
0–0–0	7.13	.19

$$t = \frac{\text{Difference of means}}{\sigma \text{ difference of means}} = 0.24 \text{ (not significant).}$$

NUMBER OF MEASUREMENTS REQUIRED FOR A TRUE SAMPLE

One hundred heads were picked at random from the 1935 bundles. The analysis of variance for the measurements of these heads is given in Table 7. The F value of 2.85, although significant, is much smaller than the F obtained from the entire number of measurements.

TABLE 7.—*Analysis of variance for 1935 Ferden wheat head measurements based upon 100 heads from each treatment.*

Source of variation	Degrees of freedom	Sum of square	Variance	Estimate of S. D.
Total	699	606.32	.867	—
Between treatment means	6	14.82	2.47	—
Within treatments	693	591.50	.866	.931

F = 2.85 (significant).

The values of t for the 100 heads are given in Table 8. These values for the differences between the fertilized and unfertilized heads are all significant, but one is only to the 5% point and all are smaller than those shown in Table 4 for the same comparisons. Also, the differences between means do not fall in the same order. As a result of the measurement of only 100 heads there were no significant differences between the head lengths of wheat grown with different fertilizers. This shows that significance is not revealed completely from samples of 100 heads.

TABLE 8.—*The differences between means, with the standard deviations of the differences and t values, obtained from 100 head samples of the 1935 Ferden wheat head measurements.*

Description	Differences	S. D. of differences	t
M_1–M_5	.46	.13	3.48**
M_1–M_7	.45	.13	3.46**
M_1–M_3	.39	.13	3.00**
M_1–$M_{2\,\&\,6}$	.38	.13	2.92**
M_1–M_4	.33	.13	2.54*

*Significance based on 5% point.
**Significance based on 1% point.

When the entire number of heads were measured the least significant mean difference was approximately 0.1 cm. Since a much larger mean difference was not significant when 100 heads were measured, it was thought desirable to determine theoretically how many heads, drawn at random from each bundle, should be measured to show that a difference of 0.1 cm between two means is significant, and then actually carry out the sampling to check theory. The standard error of each measurement, 0.931, obtained from samples of 100 heads per bundle, was used for determining the theoretical size of the sample necessary to obtain a significant difference of 0.1 cm between two means. The size of the sample, N, was found by the following formula for t:

$$(1)\ t = \frac{\text{Difference of means}}{\text{S. D. of the difference of means}} = \frac{0.10\ \sqrt{N}}{0.931\sqrt{2}} = 2.$$

The value of N found from the above formula for t is $N \geq 693$ heads.

As a check on these calculations, 700 heads were taken at random from each of the bundles. The analysis of variance for these data is presented in Table 9. The F value of 10.1 approaches that of 12.3 obtained from the entire number of heads, and as shown in Table 10 any difference as great as 0.1 cm is significant. Significance was found in the usual manner from the standard deviation value 0.928, given in Table 9. This verifies the theoretical value for N, the number in the sample.

The data in Table 10 show further that from the 700 head measurements there was not only a significant difference between the length of the unfertilized heads and those fertilized but that some fertilizers produced longer heads than did other fertilizers. The heads from the plats treated with 4–16–0 were significantly longer than those from plats treated with 4–16–8 and 0–16–8. Likewise, heads from the 4–16–4 plats were longer than those from the 4–16–8 plats. These differences are similar to those obtained from the entire number of measurements.

TABLE 9.—*Analysis of variance for 1935 Ferden wheat head measurements based upon 700 heads from each treatment.*

Source of variation	Degrees of freedom	Sum of square	Variance	Estimate of S. D.
Total	4,899	47436.37	——	——
Between treatment means	6	580.03	96.67	——
Within treatments	4,893	46856.34	9.58	.928

F = 10.1 (significant).

TABLE 10.—*The difference between means, with indication of significance, obtained from 700 head samples of the 1935 Ferden wheat head measurements.*

Description	Difference
M_1–M_7	.338**
M_1–M_3	.300**
M_1–M_4	.263**
M_1–M_2	.254**
M_1–M_6	.200**
M_1–M_5	.170**
M_5–M_7	.168**
M_5–M_3	.130**
M_6–M_7	.138**
M_6–M_3	.099*

*Significance based on 5% point.
**Significance based on 1% point.

SUMMARY

The effect of fertilizers on the length of winter wheat heads was determined by measuring large numbers of heads taken from field plats in 1935, 1936, and 1937. The significance of mean differences was shown by analysis of variance. The use of Shepherd's correction for grouped data is illustrated. A statistical study of the number of heads necessary to make a representative sample is included. From

the measurements and calculations, the following conclusions were drawn:

1. The unfertilized wheat produced longer heads in 1935 than did the fertilized wheat. In 1936 the condition was reversed. During both years, fertilizer applications greatly increased the number of heads per foot of row. The number of heads per foot of row on the unfertilized soil was almost twice as great in 1935 as in 1936. Accordingly it is concluded that when crowding is not a factor, fertilizers may be expected to increase the length of heads of winter wheat, but when the stand is so thick that the greater number of heads as a result of the fertilizer causes crowding, the length of the heads may be decreased.

2. Some fertilizers produced longer heads than did other fertilizers.

3. No differences in the results were obtained by using Shepherd's corrections for grouped data.

4. The data obtained from the measurement of 100 heads picked at random from each bundle showed that samples of 100 heads were not truly representative of the entire population.

5. When 700 heads were measured from each bundle, the significant differences were approximately the same as when all the heads were measured. The number "700" was also theoretically checked by calculating "N" from the formula for "t."

LITERATURE CITED

1. BAYFIELD, E. G. The influence of climate, soil, and fertilizers upon quality of soft winter wheat. Ohio Agr. Exp. Sta. Bul. 563. 1936.
2. COOK, R. L., and MILLAR, C. E. Five years results with fertilizers on a demonstration farm in Tuscola County. Mich. Agr. Exp. Sta. Quart. Bul. 17:116–130. 1935.
3. GRANTHAM, G. M., and MILLAR, C. E. Sandy soils. Mich. Agr. Exp. Sta. Sp. Bul. 248. 1934.
4. MILLAR, C. E. Fertilizers. Mich. Agr. Exp. Sta. Sp. Bul. 133. 1933.
5. PARSONS, F. G. The relation of number of wheat heads and increased yield as influenced by phosphate and nitrogen fertilizers. Amer. Fert., 83:5–6. 1935.
6. RICHARDSON, A. E. V., and FRICKE, E. F. Effect of nitrogenous fertilizer on the growth and yield of wheat and barley. Jour. Dept. Agr. So. Aust. 35:57–86. 1931.
7. ————, and GURNEY, H. C. The effect of nitrogenous fertilizer on the growth and yield of wheat and barley in South Australia, Part 1. Emp. Jour. Exp. Agr., 1:193–205. 1933.
8. THATCHER, L. E. The influence of certain soil amendments upon the quality of soft red winter wheat in Ohio. Jour. Amer. Soc. Agron., 18:629–648. 1926.

EXTENT OF NATURAL CROSSING IN RICE[1]

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THE inflorescence of rice is a terminal panicle of perfect flowers. Each floret or spikelet has a branched stigma, six stamens, and two well-developed lodicules. In blooming, the flowers open rapidly and usually the anthers dehisce just before or at the time the flower opens. The flowers may remain open from 1 to 3 hours.

Cultivated rice normally is self-pollinated but some natural crossing occurs. A knowledge of the extent of natural crossing in rice is of importance to the breeder, enabling him to grow material in such a manner as to eliminate crossing as much as possible and also in planning effective roguing. Available evidence indicates that natural crossing has been, and probably still is, an important factor in the origin of rice varieties. This paper presents data on the extent of natural crossing in rice varieties grown under various climatic conditions.

REVIEW OF LITERATURE

In India, Hector (2)[3] estimated 4% of natural crossing in rice in Lower Bengal; McKerral (7) 1.1% in Burma; Roy (12) from 0.1 to 2.9% in cultivated rice and 7.9% in wild rice in the Central Provinces; Parnell, *et al.* (8) from 2 to 4% in Madras. Ramiah (10) stated that, "in hybrid progenies of wild rice, the amount of natural crossing may go up to even 15 to 20% at Coimbatore, Madras"; and Kadam and Patil (5) reported from none to 4.31% with an average of 0.52% crossing in Bombay.

In Japan (Hokkaido), Akemine and Nakamura (1) found an average of 0.9% of natural crossing in 19 varieties grown close together during a 5-year period. The average maximum was 2.32% and the average minimum 0.21%. They also reported that Shimoyama (13) in Japan found 0.084% of natural crossing, and Suzuta and Tomura (14) in Formosa from 0.9 to 1.45%.

Ikeno (4) found no crossing between alternate rows of common and glutinous rice, but he reported that van der Stok in Java found from 1.3 to 4% of natural crossing, and as much as 23% in some cases. Heide (3) in Java placed varieties with respect to pollination in three groups, *viz.*, Open, variable, and closed.

Rodrigo (11) in the Philippine Islands estimated 2.4% of natural crossing in panicles bagged together. In Ceylon, Lord (6) found from 0.34 to 0.67%, and Poggendorff (9) in Australia reported an average of 0.44% of natural crossing.

This brief review indicates that the extent of natural crossing in rice probably depends both on the varieties observed and the climatic conditions under which they were grown.

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[3]Number in parentheses refers to "Literature Cited," p. 752.

MATERIAL AND METHODS

Rice varieties are classed as common or glutinous on the basis of the nature of the endosperm. Florets of glutinous varieties of rice fertilized by pollen from varieties having common kernels produce common kernels owing to the effect known as xenia. It is possible, therefore, to determine the extent of natural crossing in rice by counting the number of glutinous and common kernels present in glutinous varieties grown adjacent to common varieties. This method, involving an endosperm character, has two distinct advantages over the usual method of detecting natural crosses by means of a dominant character in F_1 plants and then growing F_2 progenies to determine if segregation occurs. First, each seed produced on glutinous plants is classified, hence large numbers are involved. Second, less labor and land are required in growing the material and in making the determinations.

Glutinous and common varieties were grown in alternate rows spaced 1, 2, and 3 feet apart. The paired varieties used began heading at about the same time. The glutinous plants were harvested when mature and the kernels were hulled and classified after they were well dried. The percentage of natural crossing determined in these experiments probably represents the maximum that might occur under the particular conditions with the varieties used because the paired varieties flowered at essentially the same time.

The pairs of varieties used were (a) Asahi Mochi (glutinous) and Colusa (common) early maturing; (b) C. I. No. 5309 (glutinous)[4] and Edith (common), also early maturing varieties but later than Asahi Mochi; (c) C. I. No. 5399 (glutinous) and Blue Rose (common) late maturing; and (d) C. I. No. 3625a (glutinous) and C. I. No. 5205 (common) midseason varieties.

An average of from 30 to 40 glutinous plants per row was grown and examined each year in Texas and Arkansas, and from 15 to 25 or more plants per row in Louisiana and California.

RESULTS OBTAINED

TEXAS

The natural crossing occurring at Texas Agricultural Substation No. 4, Beaumont, is shown in Table 1. The number of glutinous plants examined in the different years that showed crossing ranged from none to 100%. The extent of natural crossing for each pair of varieties at each row spacing varied materially from year to year. In Asahi Mochi, the average amount of natural crossing for the three spacings ranged from 0.04 in 1936 to 1.39% in 1932; in C. I. No. 5309 from 0.03 in 1936 to 0.68% in 1932; in C. I. No. 5399 from 0.25 in 1935 to 0.60% in 1936; and in C. I. No. 3625a from 0.50 in 1933 to 1.63% in 1936.

The glutinous variety C. I. No. 3625a is believed to have originated as a mutation from Shoemed because it is similar to Shoemed in all characters except that the kernels are glutinous.

Panicles of the glutinous varieties were bagged prior to blooming in

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

TABLE 1.—*Natural crossing in rice at Texas Agricultural Substation No. 4, Beaumont, Texas.*

Year	Rows 1 foot apart: Plants showing crosses %	Rows 1 foot apart: Kernels Total No.	Rows 1 foot apart: Kernels Crossed No.	Rows 1 foot apart: Kernels Crossed %	Rows 2 feet apart: Plants showing crosses %	Rows 2 feet apart: Kernels Total No.	Rows 2 feet apart: Kernels Crossed No.	Rows 2 feet apart: Kernels Crossed %	Rows 3 feet apart: Plants showing crosses %	Rows 3 feet apart: Kernels Total No.	Rows 3 feet apart: Kernels Crossed No.	Rows 3 feet apart: Kernels Crossed %
					Asahi Mochi-Colusa							
1931	94.12	9,779	34	0.35	76.47	8,521	33	0.39	64.29	6,448	15	0.23
1932	100.00	8,220	130	1.58	95.12	13,552	160	1.18	90.91	10,738	163	1.52
1933	53.49	9,597	65	0.68	55.26	12,018	46	0.38	55.26	13,067	54	0.41
1934	71.15	31,991	73	0.23	54.55	20,469	33	0.16	55.00	20,194	45	0.22
1935	60.71	7,676	38	0.50	42.42	7,504	32	0.43	62.86	10,404	33	0.32
1936	4.17	2,144	2	0.09	3.03	3,481	1	0.03	3.03	3,603	1	0.03
					C. I. No. 5309-Edith							
1932	66.67	5,119	32	0.63	80.00	6,574	41	0.62	100.00	7,150	56	0.78
1933	48.00	10,798	41	0.38	41.03	13,022	20	0.15	51.16	12,426	30	0.24
1934	23.53	19,918	22	0.11	25.49	18,492	15	0.08	32.61	16,033	17	0.11
1935	31.58	8,357	13	0.16	44.44	7,688	20	0.26	46.34	12,287	24	0.20
1936	4.35	3,162	2	0.06	3.85	2,906	1	0.03	0.00	3,284	0	0.00
					C. I. No. 5399-Blue Rose							
1932	67.86	17,409	63	0.36	95.00	24,815	84	0.34	88.00	30,771	88	0.29
1933	82.35	16,762	135	0.81	78.57	29,404	145	0.49	72.22	30,676	107	0.35
1934	87.88	14,648	153	1.04	90.70	35,441	147	0.41	78.57	25,258	133	0.53
1935	68.42	11,143	45	0.40	45.16	13,882	28	0.20	50.00	6,197	6	0.10
1936	59.57	7,867	51	0.65	55.81	9,264	53	0.57	75.51	12,344	73	0.59
					C. I. No. 3625a-C. I. No. 5205							
1932	88.89	11,386	90	0.79	92.00	17,166	142	0.83	82.14	20,873	189	0.91
1933	66.67	14,723	81	0.55	83.78	26,877	124	0.46	73.08	27,879	141	0.51
1934	100.00	36,525	594	1.63	93.02	39,672	152	0.38	85.71	25,501	146	0.57
1935	91.18	12,043	189	1.57	90.91	14,355	144	1.00	81.58	15,676	127	0.81
1936	90.91	5,988	113	1.89	89.74	9,256	144	1.56	88.37	9,245	141	1.52

1935, 1936, and 1937 to determine whether kernels of the common type might arise by mutation in glutinous varieties. In 1935 one common kernel was found on Asahi Mochi but none in the other varieties. This kernel could have resulted from a natural cross prior to bagging. In 1936, 6 common kernels, or 0.028%, were found in a total of 2,110 classified from C. I. No. 3625a. In 1937, only 1 common kernel was found in a total of 18,289 classified from bagged panicles of C. I. No. 3625a. This indicates that in C. I. No. 3625a mutation from glutinous to common kernels may occur, but if it does, the small numbers involved would not materially affect determinations of natural crossing.

ARKANSAS

The extent of natural crossing at the Rice Branch Experiment Station, Stuttgart, Ark., is given in Table 2. The number of glutinous plants examined from year to year that showed crosses varied from 10 to 100%. There was a marked variation from year to year in the extent of natural crossing for each pair of varieties in all row spacings. The average percentage of natural crossing in Asahi Mochi for all three spacings varied from 0.26 in 1931 to 1.94% in 1934; in C. I. No. 5309 from 0.25 in 1935 to 0.34% in 1936; in C. I. No. 5399 from 0.05 in 1935 to 0.25% in 1934; and in C. I. No. 3625a from 0.35 in 1936 to 0.75% in 1935.

LOUISIANA

Paired varieties were grown at the Rice Experiment Station, Crowley, La., as in the other tests, except in 1935. In that year the border rows consisted of a mixture of three or four common varieties, rather than a single variety. This change may have increased the extent of natural crossing in C. I. No. 5399 but for the other glutinous varieties the percentage was lower than in previous years. The results are shown in Table 3.

The average percentage of natural crossing in Asahi Mochi for the three spacings varied from 0.32 in 1934 to 1.07% in 1933; in C. I. No. 5309 from 0.31 in 1935 to 0.72% in 1934; in C. I. No. 5399 from 0.03 in 1934 to 0.18% in 1935; and in C. I. No. 3625a from 0.25 in 1935 to 1.59% in 1934.

CALIFORNIA

The results at the Biggs Rice Field Station, Biggs, Calif., are given in Table 4. The number of glutinous plants examined from year to year showing crosses ranged from 6.67 to 96%. The extent of natural crossing in California was much less than that recorded at the other stations. The average percentage of natural crossing in Asahi Mochi for the three spacings ranged from 0.04 in 1933 to 0.49% in 1937; and in Selection No. 299, which is similar to C. I. No. 5309, from 0.06 in 1935 to 0.34% in 1937.

EFFECT OF ROW SPACING

The natural crossing occurring in the experiments at all four stations is summarized in Table 5.

TABLE 2.—*Natural crossing in rice at the Rice Branch Experiment Station, Stuttgart, Ark.*

Year	Rows 1 foot apart				Rows 2 feet apart				Rows 3 feet apart			
	Plants showing crosses %	Kernels			Plants showing crosses %	Kernels			Plants showing crosses %	Kernels		
		Total No.	Crossed			Total No.	Crossed			Total No.	Crossed	
			No.	%			No.	%			No.	%
					Asahi Mochi-Colusa							
1931	63.04	23,582	84	0.36	58.33	20,632	48	0.23	46.51	23,389	44	0.19
1932	38.46	6,624	17	0.26	33.33	5,499	19	0.35	57.89	5,432	18	0.33
1933	57.50	11,556	41	0.34	61.11	8,874	44	0.50	54.29	6,880	36	0.52
1934	100.00	19,083	513	2.69	100.00	21,908	409	1.87	100.00	18,526	235	1.27
1935	63.64	2,156	9	0.42	36.00	4,384	9	0.21	42.86	4,796	18	0.38
					C. I. No. 5309-Edith							
1934	20.83	6,732	19	0.28	37.25	10,628	20	0.19	44.68	12,085	41	0.34
1935	27.03	5,223	14	0.27	41.94	4,928	14	0.28	39.53	9,260	20	0.22
1936	36.73	10,738	27	0.25	55.77	19,535	51	0.26	75.00	21,189	97	0.46
					C. I. No. 5399-Blue Rose							
1934	50.00	12,138	52	0.43	55.10	16,972	48	0.28	39.58	20,145	24	0.12
1935	10.81	9,167	4	0.04	10.00	9,185	3	0.03	18.75	12,170	7	0.06
1936	36.54	16,271	25	0.15	44.23	29,595	47	0.16	35.09	39,978	33	0.08
					C. I. No. 3625a-C. I. No. 5205							
1933	40.00	9,050	125	1.38	39.47	12,046	54	0.45	27.50	12,810	40	0.31
1935	52.08	11,602	84	0.72	58.00	15,478	130	0.84	59.52	12,898	86	0.67
1936	30.00	11,792	34	0.29	67.57	22,173	65	0.29	60.00	27,968	118	0.42

TABLE 3.—*Natural crossing in rice at the Rice Experiment Station, Crowley, La.*

Year	Rows 1 foot apart			Rows 2 feet apart			Rows 3 feet apart		
	Kernels			Kernels			Kernels		
	Total No.	Crossed		Total No.	Crossed		Total No.	Crossed	
		No.	%		No.	%		No.	%
				Asahi Mochi-Colusa					
1931	4,411	20	0.45	5,138	21	0.41	5,732	9	0.16
1933	2,335	21	0.90	—	—	—	1,512	20	1.32
1934	2,716	15	0.55	2,122	5	0.24	3,068	5	0.16
1935	3,566	12	0.34	2,462	7	0.28	2,599	9	0.35
				C. I. No. 5309-Edith					
1933	913	2	0.22	822	6	0.73	2,140	9	0.42
1934	3,258	19	0.58	3,677	30	0.82	4,521	33	0.73
1935	1,943	6	0.31	3,425	8	0.23	2,783	11	0.40
				C. I. No. 5399-Blue Rose					
1933	3,046	1	0.03	9,701	5	0.05	2,174	5	0.23
1934	4,353	0	0.00	8,420	2	0.02	6,321	4	0.06
1935	4,642	10	0.22	7,842	15	0.19	12,455	19	0.15
				C. I. No. 3625a-C. I. No. 5205					
1932	4,163	52	1.25	7,031	61	0.87	7,510	85	1.13
1933	526	15	2.85	1,512	0	0.00	633	0	0.00
1934	6,164	209	3.39	8,473	71	0.84	7,117	65	0.91
1935	6,840	13	0.19	8,310	17	0.20	7,913	28	0.35

In Arkansas the average percentage of natural crossing in Asahi Mochi was considerably higher in rows spaced 1 foot apart than in rows spaced 2 or 3 feet apart, but in the other states the differences for the three spacings were not large. In C. I. No. 5309 the space between the rows did not materially affect the extent of natural crossing at any station. This was also true for C. I. No. 5399. The average percentage of natural crossing in C. I. No. 3625a in Arkansas, Louisiana, and Texas, however, was considerably higher in rows spaced 1 foot apart than in rows spaced 2 or 3 feet apart.

The results indicate that a space of 3 feet between varieties of similar maturity is not sufficient to eliminate natural crossing, but it may reduce it in some cases, though hardly enough to be of practical importance.

The average percentage of natural crossing for the three spacings for Asahi Mochi was 0.84 in Arkansas, 0.48 in Texas, 0.40 in Louisiana, and 0.16 in California; for C. I. No. 5309 (selection No. 299 in California) 0.53 in Louisiana, 0.30 in Arkansas, 0.23 in Texas, and 0.16 in California; for C. I. No. 5399, 0.46 in Texas, 0.15 in Arkansas, and 0.10 in Louisiana; for C. I. No. 3625a, 0.93 in Louisiana, 0.88 in Texas, and 0.54 in Arkansas.

The average percentage of natural crossing in the four varieties at the three spacings was 0.56 in Texas, 0.51 in Louisiana, 0.48 in Ar-

TABLE 4.—*Natural crossing in rice at the Biggs Rice Field Station, Biggs, Calif.*

Year	Rows 1 foot apart: Plants showing crosses %	Rows 1 foot apart: Kernels Total No.	Rows 1 foot apart: Kernels Crossed No.	Rows 1 foot apart: Kernels Crossed %	Rows 2 feet apart: Plants showing crosses %	Rows 2 feet apart: Kernels Total No.	Rows 2 feet apart: Kernels Crossed No.	Rows 2 feet apart: Kernels Crossed %	Rows 3 feet apart: Plants showing crosses %	Rows 3 feet apart: Kernels Total No.	Rows 3 feet apart: Kernels Crossed No.	Rows 3 feet apart: Kernels Crossed %
Asahi Mochi-Colusa												
1933	18.00	18,503	16	0.09	20.00	35,632	9	0.03	40.00	39,291	14	0.04
1934	62.50	20,437	30	0.15	60.00	30,952	25	0.08	60.00	31,822	27	0.08
1935	26.67	5,438	5	0.09	20.00	4,723	3	0.06	6.67	4,228	1	0.02
1936	52.00	14,864	23	0.15	83.33	23,979	63	0.26	72.00	23,618	30	0.13
1937	88.00	17,470	63	0.36	84.00	16,065	81	0.50	96.00	13,187	85	0.64
Selection No. 299-Edith												
1934	58.33	11,461	19	0.17	62.50	19,418	23	0.12	62.50	23,320	15	0.06
1935	33.33	5,264	5	0.09	13.33	5,999	2	0.03	20.00	5,392	3	0.06
1936	72.00	13,966	31	0.22	68.00	19,994	43	0.22	60.00	20,094	23	0.11
1937	60.00	6,649	30	0.45	52.00	7,434	24	0.32	44.00	7,566	20	0.26

TABLE 5.—*Summary of the natural crossing studies in rice for the years grown at the Texas, Arkansas, Louisiana, and California stations.*

Distance from common variety	Texas			Arkansas			Louisiana			California		
	Kernels			Kernels			Kernels			Kernels		
	Total No.	Crossed		Total No.	Crossed		Total No.	Crossed		Total No.	Crossed	
ft.		No.	%		No.	%		No.	%		No.	%
Asahi Mochi-Colusa												
1	69,407	342	0.49	63,001	664	1.05	13,028	68	0.52	76,712	137	0.18
2	65,545	305	0.47	61,297	529	0.86	9,722	33	0.33	111,351	181	0.16
3	64,454	311	0.48	59,023	351	0.59	12,871	43	0.33	112,146	157	0.14
Total	199,406	958	0.48	183,321	1,544	0.84	35,621	144	0.40	300,209	475	0.16
C. I. No. 5309*-Edith												
1	47,354	110	0.23	22,693	60	0.26	6,114	27	0.44	37,340	85	0.23
2	48,682	97	0.20	35,091	85	0.24	7,924	44	0.56	52,845	92	0.17
3	51,180	127	0.25	42,534	158	0.37	9,444	53	0.56	56,372	61	0.11
Total	147,216	334	0.23	100,318	303	0.30	23,482	124	0.53	146,557	238	0.16

					C. I. No. 5399-Blue Rose							
1	67,829	447	0.66	37,576	81	0.22	12,041	11	0.09	——	——	——
2	112,806	457	0.41	55,752	98	0.18	25,963	22	0.08	——	——	——
3	105,246	407	0.39	72,293	64	0.09	20,950	28	0.13	——	——	——
Total	285,881	1,311	0.46	165,621	243	0.15	58,594	61	0.10	——	——	——
					C. I. No. 3625a-C. I. No. 5205							
1	80,665	1,067	1.32	32,444	243	0.75	17,693	289	1.63	——	——	——
2	107,326	706	0.66	49,697	249	0.50	25,326	149	0.59	——	——	——
3	99,174	744	0.75	53,676	244	0.45	23,173	178	0.77	——	——	——
Total	287,165	2,517	0.88	135,817	736	0.54	66,192	616	0.93	——	——	——
					Total All Varieties							
1	265,255	1,966	0.74	155,714	1,048	0.67	48,876	395	0.81	114,052	222	0.19
2	334,359	1,565	0.47	201,837	961	0.48	68,935	248	0.36	164,196	273	0.17
3	320,054	1,589	0.50	227,526	817	0.36	66,438	302	0.45	168,518	218	0.13
Grand total	919,668	5,120	0.56	585,077	2,826	0.48	184,249	945	0.51	446,766	713	0.16
Grand total all stations....	....	....	....	....	....	....	....	....	....	2,135,760	9,604	0.45

*Selection No. 299 used in California.

kansas, and for two varieties 0.16 in California. At all stations a total of 2,135,760 kernels was classified and of this number 9,604, or 0.45%, were common (crossed).

In 1933 and 1934 the glutinous varieties were grown at Beaumont, Texas, in three-row plats separated by at least 30 feet from any common early-maturing variety. Plants from the center rows of each plat were examined for natural crossing. In the early-maturing varieties, Asahi Mochi and C. I. 5309, the percentage of natural crossing was 0.03 and 0.05, respectively, in 1933 and 0.02 and 0.10 in 1934. In the two later-maturing varieties, the percentage of natural crossing was 0.27 and 0.30, respectively, in 1933 and 0.05 and 0.21 in 1934.

The later-maturing varieties were more exposed to foreign pollen than the early varieties, because, as the season advanced, common varieties nearer the plats began to head. The results for the early varieties indicate that natural crossing may occur at a distance of 30 feet or more.

The percentage of natural crossing within a variety probably is similar to that occurring between adjacent varieties. If this is the case, the percentages given in the preceding tables represent not more than half the natural crossing that actually occurred. Crossing within a variety, however, is of little importance for the breeder is concerned mainly with that which occurs between pure-breeding varieties and selections.

Opportunity for natural crossing occurs when flowers open before the anthers are fully developed and when the anthers fail to dehisce promptly at blooming time. Insects that feed on rice pollen may also cause natural crossing.

SUMMARY

The results presented indicate that (a) the extent of natural crossing in a given variety in the same locality varied considerably from year to year; (b) varieties differed materially in extent of natural crossing; (c) in some varieties more natural crossing occurred in rows spaced 1 foot apart than in rows spaced 2 or 3 feet apart, while in others this was not the case; (d) seasonal and environmental conditions had a marked influence on the extent of natural crossing in all varieties; and (e) much more natural crossing occurred in the Southern States than under the higher temperature and lower humidity conditions prevailing in California. The extent of natural crossing ranged from none to 3.39%, and the average for all stations was 0.45%.

LITERATURE CITED

1. AKEMINE, M., and NAKAMURA, S. Über dan Umfang und die Ursachen natürlicher Bastardbefruchtung bei Reis. [On the extent and causes of natural cross fertilization in rice.] (In Japanese) Ztschr. Pflanzenzücht., 11(1):1–22. 1 fig. 1925.
2. HECTOR, G. P. Notes on pollination and cross fertilization in the common rice plant, *Oryza sativa*, Linn. Mem. India Dept. Agr., Bot. Ser., 6(1):1–10. 1913.
3. HEIDE, F. F. R. Bloembiologische onderzoekingen betreffende sawahrijst. [Study of flowering in irrigated rice.] Meded. Alg. Proefsta. Landb. (Netherlands Indies), 15:1–49, 2 pls. 1923.

4. IKENO, S. Über die Bestäubung und die Bastardierung von Reis. [On the fertilization and bastardization of rice.] Festschr. Ztschr. Pflanzenzücht, 2:495-503. 1914.
5. KADAM, B. S., and PATIL, G. G. Natural cross-fertilization in rice. Poona Agr. Col. Mag., 25(2):53-61. 1933.
6. LORD, L. A preliminary study of natural cross-pollination of rice in Ceylon. Ann. Roy. Bot. Gard., Ceylon Jour. Sci., Sect. A, Peradeniya, 11(4):339-342. 1932.
7. McKERRAL, A. Some problems of rice improvement in Burma. Agr. Jour. India, 8(4):317-330. 1913.
8. PARNELL, F. R., AYYANGER, G. N. RANGASWAMI, and RAMIAH, K. The inheritance of characters in rice, I. Mem. India Dept. Agr., Bot. Ser., 9(2): 75-106, pls. 1-5. 1917.
9. POGGENDORFF, W. Flowering, pollination, and natural crossing in rice. A technique satisfactory for Yanco conditions. Agr. Gaz., New S. Wales, 48(12):898-904. 1932.
10. RAMIAH, K. Rice genetics. Proc. Assoc. Econ. Biol., Coimbatore, 3(1935): 51-61. 1936.
11. RODRIGO, P. A. Pollination and the flower of rice. Philippine Agr., 14(3):155-171. pl. 1-2, fig. 1. 1925.
12. ROY, S. CHANDRA. A preliminary classification of the wild rices of the Central Provinces and Berar. Agr. Jour. India, 16(4):365-380. 1921.
13. SHIMOYAMA, C. On the degeneration of varieties of rice. (In Japanese) Rpt. Jap. Agr. Assoc. No. 465:27-30. 1920.
14. SUZUTA, I., and TOMURA, C. On the natural cross fertilization of the rice plant. (In Japanese) Formosan Agr. Rev. No. 184(16):214-240. 1922.

THE CORRELATION AMONG VARIOUS CONSTITUENTS OF FORAGE PLANTS[1]

J. E. GREAVES[2]

DURING the fall and winter of 1931, 72 samples of forage plants were collected on the Trout Creek winter range in Juab County, Utah (2)[3]. They represented the following 16 species which composed the bulk of the forage plants in this district:

Artemisia tridentata	*Atriplex confertifolia*
Artemisia nova	*Gutierrezia sarothrae*
Artemisia spinescens	*Chrysothamnus nauseosus*
Ephedra nevadensis	*Chrysothamnus viscidiflorus*
Kochia vestita	*Oryzopsis hymenoides*
Hilaria jamesii	*Salsola pestifer*
Atriplex canescens	*Juniperus utahensis*
Atriplex nuttallii	*Eurotia lanata*

Great care was used in their collection. From 6 to 8 pounds of leaves and stems, the portions ordinarily browsed by sheep, were hand picked from representative plants. The whole sample was dried, ground, and then sampled for analyses. From three to six samples of each plant species were collected in this manner from different localities and these were analyzed separately for crude fibre, crude fat, crude protein, ash, calcium, magnesium, phosphorus, and sulfur according to the methods of the Association of Official Agricultural Chemists (1) The nitrogen-free extract was calculated by subtracting the crude fibre, crude fat, crude protein, and ash from the total dry weight.

The correlation among the various constituents was then calculated according to the following formula given by Wallace and Snedecor (3):

$$r = \frac{\Sigma AX-(\Sigma A)\ Mx}{\sqrt{\Sigma A^2-(\Sigma A)\ Ma}\ \sqrt{\Sigma X^2-(\Sigma X)\ Mx}},$$ where A and X equal the two variables and $Mx = \frac{\Sigma X}{N}$ and $Mz = \frac{\Sigma A}{N}$.

The mean ash content of the 16 plants varied from 4.45% in the case of *Juniperus utahensis* to 21.55% in the case of *Artemisia spinescens*. There was also a great variation in the ash of the same species probably due to age, soil, and amount of water received during the growing period. Seven of the plants carried over 10% ash, three having 20%. About half of the plants analyzed carried more ash than alfalfa hay. In Table 1 is given the correlation found to exist between ash and the other constituents determined.

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[3]Figures in parenthesis refer to "Literature Cited," p. 759.

TABLE 1.—*Correlation between ash of 16 forage plants and other constituents.*

Constituent	r	Constituent	r
Calcium	0.316	Crude protein	−0.056
Magnesium	0.784	Crude fat	−0.819
Phosphorus	−0.350	Crude fiber	0.083
Sulfur	0.542	Nitrogen-free extract	0.157

A highly significant relationship between the ash of these forage plants and the quantity of magnesium, sulfur, and calcium which they carry is shown by the respective correlations. However, a high ash content is associated with a low crude fat content, and likewise the phosphorus content is negatively correlated with the ash content. There is probably little or no relationship between the ash content of these plants and their crude protein or nitrogen-free extract content.

The calcium content of these plants varied from 0.40% in the *Hilaria jamesii* to 2.10% in the *Salsola pestifer*. They were grown in calcareous soil and would all be classed as high in calcium, yet a wide variation existed in the same species.

From Table 2 a significant correlation is shown to exist between the calcium content of these plants and the ash, calcium and sulfur, and calcium and magnesium content. The soils from which these plants were collected contained large quantities of calcium, magnesium, and sulfur; hence, the close relationship between available nutrients in the soils and the concentrates in the plants. The quantity of phosphorus in the soil is high, yet that available to the growing plant decreases with the soil concentration of calcium; thus the reason for the negative correlation between calcium and phosphorus. From the viewpoint of animal nutrition this is very significant and points to the conclusion that many of these plants when fed to animals should be supplemented with a sodium or potassium salt of phosphorus. The fat and carbohydrate contents of these plants decrease as the calcium increases, as indicated by the correlations, showing that the nutritive values of these high-calcium forage plants are as a rule less than the low-calcium forage plants.

TABLE 2.—*Correlation existing between calcium and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	0.361	Crude protein	0.219
Magnesium	0.304	Crude fat	−0.284
Phosphorus	−0.532	Crude fibre	0.054
Sulfur	0.396	Nitrogen-free extract	−0.503

The mean magnesium content of these plants varies from 0.15% in the cases of *Hilaria jamesii* and *Oryzopsis hymenoides* to 0.91% in the case of *Kochia vestita*. The average for all was 0.41%. The variation between samples is also wide, for example, one sample of *Salsola pestifer* carried only 0.04% magnesium, whereas a different sample grown in a different locality carried 0.21%.

As shown by the correlation coefficients (Table 3), there is a direct relationship between the magnesium, ash, and calcium content of these forage plants and a negative correlation between the magnesium and crude fat. Apparently no relationship was found to exist between the magnesium and the other determined constituents.

TABLE 3.—*Correlation existing between magnesium and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	0.784	Crude protein	0.096
Calcium	0.304	Crude fat	−0.264
Phosphorus	0.208	Crude fibre	−0.109
Sulfur	0.173	Nitrogen-free extract	−0.067

The mean phosphorus content of the 16 species of plants was 0.18% with a wide variation within a species and between different species. Nearly all of these 16 dominant forage plants would meet an animal's phosphorus needs, but nearly all were carrying excessive quantities of calcium, hence the phosphorus-calcium ratio is out of balance. There is a highly significant correlation (Table 4) between phosphorus and crude protein and phosphorus and crude fat with an inverse relationship between the phosphorus and ash and phosphorus and crude fibre. Hence, insofar as these plants are concerned, the phosphorus content is a good measure of the nutritive value of the plant. However, in order to get the best results from feeding these plants, a phosphorus supplement should be available.

TABLE 4.—*Correlation found between phosphorus and other constituents of forage plants.*

Constituents	r	Constituents	r
Ash	−0.350	Crude protein	0.444
Calcium	−0.532	Crude fat	0.677
Magnesium	0.208	Crude fibre	−0.530
Sulfur	0.176	Nitrogen-free extract	−0.151

The mean sulfur content of the 16 plants varied from 0.14% in the case of *Hilaria jamesii* to 0.59% in *Atriplex nuttallii*. Many of the plants are richer in sulfur than alfalfa; however, before they could be compared from a nutritive standpoint one must know the percentages of the sulfur which is organic. The fact that "r" is a significant value in the cases of calcium and magnesium (Table 5) indicates that the plants carry inorganic sulfur. The organic sulfur would likely all be contained in the crude protein where a correlation of 0.491 is shown.

TABLE 5.—*Correlation between sulfur and other constituents of forage plants.*

Constituents	r	Constituents	r
Ash	0.542	Protein	0.491
Calcium	0.396	Fat	−0.238
Magnesium	0.173	Crude fibre	−0.348
Phosphorus	0.176	Nitrogen-free extract	−0.227

All of the plants were rather poor in crude protein. Only one, *Artemisia spinescens*, is as rich in crude protein as alfalfa. *Juniperus utahensis*, *Gutierrezia sarothrae*, *Chrysothamnus nauseosus*, and *Chrysothamnus viscidiflorus* have a mean crude protein percentage equal to that of timothy hay; whereas, *Oryzopsis hymenoides* and *Hilaria jamesii* carry no more crude protein than oat and barley straw.

The correlation (Table 6) is high between the crude protein and phosphorus and crude protein and sulfur which may indicate that considerable of the sulfur and phosphorus are in the organic form.

TABLE 6.—*Correlation between crude protein and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	-0.056	Sulfur	0.491
Calcium	0.219	Crude fat	0.177
Magnesium	0.096	Crude fibre	-0.342
Phosphorus	0.444	Nitrogen-free extract	-0.165

A wide variation existed in the crude fat between different families of these plants and likewise between samples collected from the same species. For example, some samples of *Chrysothamnus viscidflorus* contained five times as much crude fat as did others. The crude fat content of *Juniperus utahensis* was 30 times that of *Hilaria jamesii*. All of the plants analyzed, except *Artemisia spinescens*, *Salsola pestifer*, *Oryzopsis hymenoides*, *Atriplex confertifolia*, and *Hilaria jamesii*, contained more crude fat than dry alfalfa hay. As shown by the data in Table 7, the crude fat and phosphorus were positively correlated with a negative correlation between crude fat and ash, crude fat and calcium, crude fat and magnesium, crude fat and sulfur, and crude fat and crude fibre.

TABLE 7.—*Correlation between crude fat and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	-0.819	Sulfur	-0.238
Calcium	-0.284	Crude protein	0.177
Magnesium	-0.264	Crude fibre	-0.342
Phosphorus	0.677	Nitrogen-free extract	-0.165

Of the 16 forage plants analyzed, all except 6 have a mean fibre content of over 20%. *Ephedra nevadensis* carried 40% crude fibre; however, the percentage of crude fibre varied in the same species, old plants carrying much more than young plants. Leaves, stems, and stocks of some plants are tender, whereas in other plants they are woody. *Ephedra nevadensis* with its 40% of crude fibre carried 2.5 times as much as did either *Kochia vestita* or *Atriplex canescens*.

As the crude fibre increased, the phosphorus, crude protein, crude fat, and nitrogen-free extract all decreased, thus indicating that a plant having a high crude fibre content is exceptionally low in nutritive value. The correlations are shown in Table 8.

TABLE 8.—*Correlation between crude fibre and other constituents of forage plants.*

Constituent	r	Constituent	r
Ash	0.083	Sulfur	0.348
Calcium	0.054	Crude protein	−0.342
Magnesium	−0.109	Crude fat	−0.513
Phosphorus	−0.530	Nitrogen-free extract	−0.535

The mean nitrogen-free extract of the 16 species of forage plants varied from 35.5% to 50.1%. There was a variation of nitrogen-free extract in the same species of from 5 to 25% between the minimum and the maximum.

As shown by the correlation coefficient (Table 9), with the single exception of fat, all other constituents determined decreased as the nitrogen-free extract increased, the value of "r" being in the cases of calcium, crude fat, and crude fibre highly significant.

TABLE 9.—*Correlation between nitrogen-free extract and other constituents of forage plants.*

Constituents	r	Constituents	r
Ash	0.157	Sulfur	−0.227
Calcium	−0.502	Crude protein	−0.165
Magnesium	−0.067	Crude fat	0.325
Phosphorus	−0.151	Crude fibre	−0.535

SUMMARY

Seventy-two samples, representing 16 species of forage plants growing on the Trout Creek winter range in Juab County, Utah, were analyzed for calcium, magnesium, phosphorus, sulfur, crude fat, crude protein, and nitrogen-free extract. The correlation existing between pairs of these constituents has been calculated with the following results:

A highly significant correlation was found to exist between ash and calcium, ash and magnesium, ash and sulfur, calcium and magnesium, calcium and sulfur, phosphorus and crude protein, phosphorus and crude fat, and sulfur and crude protein.

A highly significant negative correlation was found to exist between ash and phosphorus, ash and crude fat, calcium and phosphorus, calcium and nitrogen-free extract, phosphorus and crude fibre, sulfur and crude fibre, crude fibre and crude protein.

These results indicate that the organic sulfur varies, and it is necessary to determine the quantity which is inorganic before one can state its nutritive value. Insofar as these plants are concerned, a total phosphorus determination is a good indication of the nutritive value of the plant because phosphorus and sulfur, phosphorus and protein, and phosphorus and crude fat vary directly, whereas the phosphorus and crude fibre and phosphorus and total ash vary inversely. The fact that the phosphorus and calcium vary inversely indicates that from the nutritional standpoint one must balance the calcium in relation

to the phosphorus. This unbalanced relationship may be the reason why supplements used in connection with these forage plants give such poor results.

LITERATURE CITED

1. Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. Washington, D. C. 1930.
2. Esplin, A. C., Greaves, J. E., and Stoddart, L. A., A study of Utah's winter range: Composition of forage plants and use of supplements. Utah Agri. Exp. Sta. Bul. 277. 1937.
3. Wallace, H. A., and Snedecor, George W., Correlation and Machine Calculation. Iowa State College, Ames, Iowa. 1931.

SELF-POLLINATION IN RAPE[1]

VON G. SUN[2]

IT is recognized that in breeding groups of plants which are frequently or naturally cross-pollinated, some method of controlling pollination must be developed in order to obtain selfed seed and isolate inbred lines. Considerable attention has been focused on methods of selfing rape since the writer began his rape breeding experiments in 1933.

From a practical standpoint any satisfactory method of self-pollination must be (a) simple in operation, (b) inexpensive, and (c) must ensure an adequate amount of selfed seed. This study is a report of different methods of selfing rape in order to meet the above requirements.

LITERATURE REVIEW

Pearson (3)[3], in studies of breeding methods with cabbage, found that the application of pollen from the same plant was as effective as foreign pollen if applied at the proper time. He used a method of pollinating in the bud stage as a means of obtaining selfed seed. The inflorescences were enclosed in paper bags to prevent crossing by insects.

Kakizaki and Kasai (2) found that bud pollination in *Brassica pekinensis* and *Raphanus sativus* materially increased the amount of selfed seed obtained. This was true particularly in highly self-incompatible plants.

Stout (4) found that selecting during generations of selfing in *Brassica pekinensis* produced no completely self-fertile lines. He found that the greatest amount of selfed seed was obtained in the middle of the flowering period.

In 1934, Sun (5) obtained an average of 63% seed setting in open-pollinated inflorescences of rape as compared with only 21% in inflorescences enclosed in glassine bags to prevent crossing. In 1935 the percentages of seed set were 72 and 23, respectively. While the amount of seed set when selfing was markedly lower than in open-pollinated inflorescences, it would be sufficient for continued inbreeding.

MATERIAL AND METHODS

Three different methods of obtaining selfed seed in inbred lines of rape were studied, *viz.*, (a) without removal of the terminal buds, (b) with removal of the terminal buds, and (c) bud pollination with terminal buds removed. Paper bags were used to enclose the inflorescences to prevent crossing.

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[2]Associate Professor. The writer wishes to express his thanks to Messrs. S. J. Young and P. Kong, senior students in the College of Agriculture of the National University of Chekiang, for data made available in the course of the experiment.

[3]Figures in parenthesis refer to "Literature Cited," p. 762.

It had been observed in previous studies that the indeterminate habit of growth of the inflorescence led to poor development of the silliqua due to elongation of the branches. By removing the terminal buds such elongation could be stopped.

At the time of early blooming, about March 13 to 20, 1937, four plants of each inbred line of rape in the nursery were selected at random and each plant treated in each of the three ways given above. Under method A, a single inflorescence on each plant was enclosed in a paper bag; for method B 10 buds were left on each inflorescence and the flowers allowed to self; while for method C 10 buds in each inflorescence were pollinated by hand, using pollen from the same plant. Paper bags 4 x 14 inches in size were used to enclose the inflorescences under all three methods. Any flowers which appeared to be open were removed before bagging. The number of seeds obtained from each inflorescence was determined after harvest and the data analyzed by the analysis of variance.

EXPERIMENTAL RESULTS

The number of seeds set on the inflorescences of four plants per inbred line by each of the three methods of selfing is given in Table 1.

TABLE 1.—*Number of seeds set in four inflorescences by three methods of selfing in each of 10 inbred lines of rape grown in 1937.*

Strain No.	Methods of selfing*			Average
	A	B	C	
95-1-9	27	10	117	51
92-2-1	64	36	291	130
35-1-17	218	48	284	183
14-2-1	270	43	452	255
Number lost	29	4	493	175
72-2-1	359	108	395	287
Number lost	26	27	273	109
97-3-8	98	33	74	68
91-5-2	23	1	185	70
91-5-2	172	0	256	143
Average	129	31	282	

*A = without removal of terminal buds.
B = with removal of terminal buds.
C = bud pollination of 10 buds per inflorescence, terminal buds removed.

In the above table it is seen readily that the greatest amount of seed was obtained by method C i.e., by bud pollination. The results by methods B and C are directly comparable, since 10 buds were left on each inflorescence. By method A the terminal buds were not removed, allowing a greater possible number of flowers to develop and set seed. In spite of the greater number of flowers under method A, less than half as much seed was obtained on the average as with method C. The different strains varied considerably in fertility.

A test was set up also to determine whether there was a difference in amount of selfed seed obtained on the same inflorescence in differ-

ent parts of the flowering period. Twenty plants in each of two inbred lines were selected and three comparable branches on each plant bagged on the same day. Only 10 of the largest, unopened buds were left on each branch. These were selfed artificially, one plant per line being selfed on each of the following days: March 16, 22, and 28. The total number of silliqua and number of seeds obtained from each of the three treatment periods are given in Table 2.

TABLE 2.—*Number of silliqua and number of seeds obtained from three treatment periods of 20 plants selected from each of two inbred lines.*

Color of seed of inbred line	No. of silliqua for selfing period			No. of seeds for selfing period		
	Mar. 16	Mar. 22	Mar. 28	Mar. 16	Mar. 22	Mar. 28
Red	10	37	39	60	178	83
Yellow	22	26	31	61	67	77

It is apparent that the number of seeds obtained was greatest in the middle of the flowering period in the case of the red-seeded lines. There seems to have been essentially no difference in different periods of selfing in the yellow-seeded line.

SUMMARY

1. Bud pollination proved to be the most effective method for obtaining selfed seed in rape.

2. Some evidence was found that the middle of the flowering period may be the most efficient stage for artificially selfing rape.

3. Covering the inflorescence with a paper bag gave sufficient seed so that this method appears feasible as a practical method of selection in self-pollinated lines.

LITERATURE CITED

1. BECKER, J. Handbuch des gesamten Gemüsebaues. Paul Parey, Berlin. 1929.
2. KAKIZAKI, Y., and KASAI, T. Bud pollination in cabbage and radish. Some examples of conspicuous "Pseudo-fertility" in normally self-incompatible plants. Jour. Hered., 24:359–60. 1933.
3. PEARSON, O. H. Breeding plants of the cabbage group. Calif. Agr. Exp. Sta. Bul. 532. 1932.
4. STOUT, A.B. Pollen tube behavior in *Brassica pekinensis* with reference to self-incompatibility in fertilization. Amer. Jour. Bot., 18:686–95. 1931.
5. SUN, V. G. Effects of self pollination in rape. Jour. Amer. Soc. Agron., 29:555–567. 1937.

INDUCING GERMINATION IN *ORYZOPSIS HYMENOIDES* FOR RANGE RESEEDING[1]

L. A. STODDART AND K. J. WILKINSON[2]

VAST areas of range land in the western United States are now or were formerly dominated by the perennial bunch-grass *Oryzopsis hymenoides* (Roem. and Shult.) Ricker, known commonly as Indian ricegrass. Since this grass is a climax species and as such has demonstrated its ability to thrive under climatic conditions existant throughout most of the dry lands west of the Great Plains, it is ecologically sound that it be given consideration in many revegetation programs in the West.

Indian ricegrass grows from Canada to New Mexico and in all states west of Montana, Nebraska, and Texas. It thrives best on foothills and plains, especially where the soil is well aerated as in rocky or sandy areas. Even rather rapidly shifting sands hold no peril for this grass, as it can elongate its basal internodes, produce adventitious roots at the nodes, and thus re-establish itself at a higher level. *Oryzopsis hymenoides* is typically without rhizomes and forms an open and widely spaced bunch cover. It is highly valued as a forage species, and it is remarkably resistant to heavy grazing.

Because of the apparent adaptability of Indian ricegrass to western ranges many trial seedings have been made by various agencies, practically all of which have proved unsuccessful, apparently because of poor seed germination. As is the case with most native grasses, this species has had very little study with regard to viability of the seed and possible treatments for stimulation of germination. It is believed that information concerning such factors is essential before the practicability and economic feasibility of the use of this species in reseeding programs can be determined.

LITERATURE

Although literature on germination of seeds and methods of increasing and hastening germination is abundant, that dealing with *Oryzopsis hymenoides* seed is very rare.

The work of Huntamer[3] indicated a considerable variation in the viability of *Oryzopsis hymenoides* seed collected from different sections of the state of Washington. When the seeds were treated with concentrated sulfuric acid to weaken the indurate black seed coats, satisfactory germination was obtained from most collections. She concluded that acid treatment performed the same function as mechanical scarification in removing the seed coats which were believed to be the cause of low germination. She likewise concluded that since seeds soaked in water increased considerably in weight, intact seed coats

[1]Contribution from the Range Management Department, Utah Agricultural Experiment Station, Logan, Utah. Publication approved by the director May 24, 1938. Received for publication June 6, 1938.

[2]Range ecologist and Student, respectively.

[3]HUNTAMER, M. Z. Dormancy and delayed germination of *Oryzopsis hymenoides*. Unpublished thesis. Wash. State College. Pullman, Wash., 1934.

did not restrict water absorption, and hence their effect upon germination was one of mechanical resistance rather than of physiological restriction of the entrance of water.

PROCEDURE AND RESULTS

Seeds of *Oryzopsis hymenoides* were obtained from six areas in Utah varying ecologically from salt-desert winter range to high-mountain summer range. The seed varied in age from a few months to 6 years. Untreated samples of each collection were subjected to standard conditions for germination (Petri dish method) for periods of 1 month with entirely negative results. This indicated that the normal seeds were probably in a permanently dormant state and that the problem was not merely one of delayed germination. To determine the cause for this lack of germination, a number of examinations and experiments were instigated.

Several seeds were opened to determine the condition of the embryo within the seed coat. Less than half of the seeds of most collections so examined contained a developed embryo. The majority could not possibly germinate, since the black shell-like coat was entirely empty. An examination was made in an attempt to correlate size, color, and shape of the seed with development of the embryo. In the course of this examination a great variation in the size of individual seeds of *Oryzopsis hymenoides* was noted. In studying the effect of size upon development of the embryo the seed was separated into the following five size classes by a screen-type seed separator: (1) Very large, over 1/12-inch diameter; (2) large, under 1/12 but over 1/14-inch diameter; (3) medium, under 1/14 but over 1/15-inch diameter; (4) small, under 1/15 but over 1/18-inch diameter; and (5) very small, under 1/18-inch diameter.

Examination of these size classes separately indicated that size and general superficial appearances of the seed were no index to internal development. A definite correlation existed, however, between the weight of the seeds and their embryo development, developed seeds being notably heavier.

To separate full from empty seeds, tests were made on the tendency of the seeds to float or sink in various liquid media. The full seeds, being heavier, were found to settle in liquid much more readily than the empty lighter seeds. Alcohol was the most efficient separating liquid found. Very rarely did full seeds float on the surface of alcohol, while trials involving several thousand seeds showed 91% of the seeds which sunk immediately to be full. Water at room temperature was found almost as effective as alcohol in separating the seeds provided they remained in the water for a considerable time. Table 1 shows the percentage of seeds in various size classes which sunk in water after a brief churning.

From Table 1 it can be seen that practically all seeds sinking in water within 24 hours had developed embryos, whereas less than 50% of the original seed had developed embryos.

Germination tests were conducted to determine the viability of

TABLE 1.—*Percentage of Oryzopsis hymenoides seed which sunk in water after various time intervals and the percentage of these which contained developed embryos.*

Seed sample No.	No. of seeds	After 5 min.		After 24 hrs.		After 48 hrs.		After 72 hrs.	
		Sinking, %	Developed, %	Sinking, %	Developed, %	Sinking, %	Developed, %	Sinking, %	Developed, %
1	2,000	5.8	100	13.5	100	25.8	69.0	37.6	52.2
2	2,000	5.8	100	15.0	100	32.7	68.3	49.4	52.3
3	5,000	10.8	100	20.0	98.3	—	—	37.3	48.9

seeds sinking after various time intervals in water. Those sinking within 5 minutes were found to germinate an average of 22.5%. Those sinking after 5 minutes but within 24 hours germinated only 2%. No germination was obtained from seeds sinking after 24 hours. From these studies it is concluded that only seeds which sink in water within 5 minutes have a reasonable chance to grow. Those sinking after this period even though apparently well developed are, in general, not viable.

GERMINATION TESTS

After obtaining potentially viable seed by the above described method attempts were made to increase the germination of this seed by several artificial treatments. These germination tests were carried on in Petri dishes, using sterilized blotters and sterilized water. A number of chemical and physical treatments were tried, including concentrated sulfuric acid (36N), acetic acid (0.01N), dilute hydrochloric acid (0.001N), butyric acid (0.08N), thicurea (5 and 3% solutions), sodium carbonate, stratification in sand at 0° ± F, scarification, dry heat (80° C), alternate heat and cold, and removal of the seed coat by use of a knife.

Of these treatments only three resulted in any increase in germination, these three being concentrated sulfuric acid, scarification, and removal of the seed coat; however, the increase from scarification was too slight to be of practical value. It will be noted at once that all of these are methods which remove or weaken the seed coat; hence the cause of low germination in *Oryzopsis hymenoides* is presumably an impermeable or mechanically resistant seed coat.

The removal of this coat is undoubtedly brought about in nature by decay over a period of several months. Observations by the authors and by other workers indicate that a low germination may be obtained by allowing the seed to remain in soil for several months, during which time the coat rots away. Germination percentages of 1 to 4 have been obtained by the authors after 8 months from untreated seed planted in greenhouse flats. A much more rapid and complete germination, however, is desirable for range reseeding.

Seeds from which the coat had been mechanically removed by peeling with a knife germinated immediately, but this method is obviously impossible on a large scale. Further tests revealed the fact

that acid was equally efficient as a means of removing the seed coat and hence study was confined entirely to the acid treatment.

Experience with the use of sulfuric acid on Indian ricegrass very soon brought to light the fact that different sized seeds behaved very differently in acid, the smaller requiring much less time in acid than the larger in order to germinate. Hence, seed sinking in water within 5 minutes was separated into the five size classes previously described, and samples of each class were treated with 36N acid, just enough to cover the seeds, for time periods up to 150 minutes. Germination was usually effected within 3 days but occasional seeds required 15 to 20 days. Table 2 shows the average percentage germination that was obtained from each size class in Petri dishes.

TABLE 2.—*Average percentage of Oryzopsis hymenoides seed in five size classes which germinated after treatment with concentrated sulfuric acid for various time intervals.*

Size class	Minutes submerged in acid										
	0	15	30	45	60	75	90	105	120	135	150
Very small	0	16	42	21	1	0	0	0	0	0	0
Small	2	14	48	48	10	1	0	0	0	0	0
Medium	0	9	28	57	42	37	9	8	0	0	0
Large	0	0	3	28	42	42	38	44	3	3	0
Very large	0	0	0	5	46	62	51	45	15	11	1

It can be seen from Table 2 that little or no germination takes place until the seed coat has been destroyed by acid and that the seeds may remain in acid for a considerable time thereafter before their germination is greatly reduced. No single time period gives a maximum germination for all size classes and, hence, to obtain maximum germination a separation of the seed into size classes is essential. There is considerable doubt, however, as to the practicability of separation of seed on a large scale because of the time and difficulty involved. Owing to this limited possibility of separating seed into size classes, further tests were conducted on unseparated seeds to determine the loss of seed involved by omitting this operation.

Data presented in Table 2 indicate that, by separation into size class, a maximum average germination of about 50% can be obtained. Tests on unseparated seed gave a maximum germination of 26% after a 45-minute acid treatment. The average of several treatments of 45- and 60-minute durations was 22.5%. It is apparent, then, that reseeding programs in which seed was not separated would require over twice the quantity of seed required if a separation could be obtained. The advisability of separation could be determined for each seeding upon the basis of cost of seed and cost of separation into size classes.

Test plantings of acid-treated *Oryzopsis hymenoides* seed in soil under both greenhouse and nursery conditions brought to light the fact that the seedlings are very susceptible to fungal growth prior to emergence. Tests using seeds from which the coats had been mechani-

cally removed showed no great difference between the susceptibility of seedlings from acid-treated and non-treated seed. In unsterilized soil from 70 to 95% of the germinated seeds failed to emerge from the soil. Sterilization of the soil reduced this mortality to between 40 and 50%. Successful emergence from the soil could be obtained from only an average of 12 seeds from each hundred mixed size acid-treated seeds, whereas the same seed would give an average of 22.5% germination in a Petri dish. Numerous planting depths and soil textures were tried unsuccessfully in an attempt to increase the percentage of successful emergence. Practically all plants emerging from the soil became successfully established and could easily be grown to maturity in either greenhouse or nursery.

Germination tests on seeds that had been acid treated and stored for periods up to 6 months indicated that no harm resulted from dry storage of treated seed. Commercial seed companies might, therefore, treat large quantities and dispense them at later dates without loss.

DISCUSSION

By two simple treatments the germination of seed of *Oryzopsis hymenoides* can be raised to a point at which reseeding range land with this species has a reasonable opportunity to be successful. Without treatment it is doubtful if reseeding will be successful. For example, seed from Tooele County, Utah, collected in 1935 gave, two years later, no germination without acid treatment; a maximum of 2% germination with acid treatment alone; 26% with segregation of the empty seed by water plus acid treatment; and 53% with segregation of the empty seed by water, separation into size classes, plus acid treatment. In soil, however, only 28% of the plants receiving this latter treatment could be expected to establish themselves successfully and to mature. Omitting the segregation into size classes resulted in emergence and establishment of only 13%. It would appear, therefore, that these treatments are absolutely essential to a reseeding program involving *Oryzopsis hymenoides*. It is believed that necessary equipment and materials could be secured at relatively low cost which would be adequate to large-scale treatment of seed.

SUMMARY

Oryzopsis hymenoides, though it is a widespread dominant throughout much of the western United States, has not been successfully used to reseed depleted areas.

Germination tests without seed treatment gave negative results which is believed to account for the failure in numerous reseeding programs.

Examination revealed that often over half the seeds lack a developed embryo and hence could never germinate. Undeveloped seeds can be practically removed by submerging the seed in water for 5 minutes. Most undeveloped seeds will float while most developed seeds will sink.

Numerous mechanical and chemical tests to increase the germination of developed seeds indicated that the firm seed coats prohibited

germination and that this could best be remedied by treating the seeds with concentrated sulfuric acid.

The period of time that seeds should be treated with acid varies with the size of seed, very small seeds requiring only 15 to 45 minutes and very large seeds requiring from 60 to 120 minutes. Therefore, separation of the seed into size classes is recommended for maximum success.

An average germination of 50% was attained by these treatments and slightly more than half of the seed germinating became successfully established and matured in soil.

It is concluded that these or similar seed treatments are essential to an economic reseeding program involving *Oryzopsis hymenoides*.

EFFECT OF WEATHER VARIANTS ON FIELD HARDENING OF WINTER WHEAT[1]

C. A. SUNESON AND GEORGE L. PELTIER[2]

IN the course of controlled freezing experiments at Lincoln, Nebr., extending over a 6-year period, certain data have accumulated that show wide seasonal and intraseasonal variations in field hardiness during the period of hardening development, i.e., November, December, and early January. These variations are of interest in themselves but also are of value in the analysis of weather influences on hardening under field conditions. The observed variations seem to be closely related to differences in radiation, temperature, day length, and precipitation. These weather factors, as well as others, have been considered in the literature concerning cold hardening of crop plants but usually in empirical experiments which have differed widely from actual field conditions.

REVIEW OF LITERATURE

The extensive literature on cold resistance and hardening has been reviewed by others, so only recent articles concerning one or more of the climatic variables herein considered are reviewed here.

Tysdal (16)[3] reported that in alfalfa shortening day-lengths had as great a hardening influence as lowering temperatures. The same author, as well as Saprygina (9), who employed spring wheats, found day-lengths approximating those of our shortest winter days most conducive to hardening.

Tysdal (16) also emphasized the importance of light intensity, especially under light deficiency conditions. A role for light might also be inferred from the work of the authors (13), wherein reduction in leaf area of winter wheats reduced hardiness; and from the work of Tumanov, *et al.* (15), who stated that carbohydrate exhaustion and not lack of aeration is responsible for killing of wheat under prolonged snow cover. Similarly, Salmon (8) showed hardiness differences in successive day and night freezing tests; and Dexter (2) mentioned the importance of accumulation and maintenance of high available carbohydrate reserves in the plant preliminary to efficient cold temperature hardening. Akerman (1) associated high sugar content with hardiness in winter wheats. The authors (12) have called attention to the superior conditioning effect of high temperatures, showing that greenhouse plants grown at 77° F had a greater capacity to harden under subsequent constant low temperatures than plants grown at 60° F.

The hardening influence of low temperatures is generally recognized. The authors (12) have shown that hardiness in winter wheat reaches a maximum after 3 weeks of exposure to constant temperatures between 29° and 35° F.

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[3]Numbers in parenthesis refer to "Literature Cited," p. 778.

Tysdal (16) considered a 2-week period of constant low temperature hardening as optimum for alfalfa, because in his earlier work a decline in hardiness after more than 3 weeks of such exposure had been shown.

Hill and Salmon (5) suggested that hardening by exposure to low temperatures was essential for the expression of normal relative hardiness of diverse wheat varieties; but Salmon (8) found it was not essential for a proper appraisal of rye varieties. Worzella (17) stated that he obtained maximum differentiation between wheat varieties when exposed for only 15 hours at 34° F but observed normal ranking of varieties in lots frozen direct from a warm greenhouse. The hardened condition in winter wheat may best be maintained by environments favoring the conservation of organic food reserves, according to Dexter (3). Both Salmon (8) and Tumanov (14) emphasized that acquired hardiness may be dissipated rapidly by exposure to warm temperatures.

Soil moisture acts as a buffer against sudden temperature changes, as was shown by both Salmon (8) and Tysdal (16); but Gruentuch (4) specifically pointed to high soil moisture as a factor reducing the degree of plant hardening. Newton (7) earlier found that a reduction in available water content within the plant was the most important quantitative change associated with hardiness. Scarth and Levitt (10) have shown that low temperatures or drought increase permeability of the cell membranes to water. They found permeability more closely correlated with hardening than any other physical character.

EXPERIMENTAL METHODS

In the experiments reported herein freezing tests were made at frequent but irregular intervals during the fall and into January of each of six seasons, 1930–31 to 1935–36, inclusive. In some years occasional tests were made in late January and later. Data were obtained from approximately 90,000 plants grown in 728 flats. Numerous varieties, some more hardy and others less hardy than the Nebraska 60 standard, were compared. The plants emerged about October 18 in all seasons. These plants were grown and frozen and their survival determined in a comparable manner each year. The technic has been described previously (11) and has been shown to approximate closely natural freezing with regard to both lethal temperatures and comparative varietal reaction.

The weather data presented were compiled from published records of the U. S. Weather Bureau Station at Lincoln, Nebr.

In this study the degree of hardening has been based upon the freezing temperature necessary to kill 40 to 60% of Nebraska 60 wheat plants. Nebraska 60 is intermediate in hardiness. It was found that when the freezing temperature used in the tests differed by more than 2° F above or below that required for killing 40 to 60% of Nebraska 60 plants, complete killing of some varieties or no killing of others usually occurred. Variations in the level of hardiness occurred from week to week and season to season, making it necessary to predict a new effective freezing temperature within the above range for each test. During the first season only three out of five experiments on the average were successful, the others being frozen either too lightly or too severely. In the last or sixth season, however, when radiation, temperature, day-length, and precipitation influences were recognized, a determination of effective freezing temperatures and satisfactory differentiation of varieties was secured in all experiments.

EXPERIMENTAL RESULTS

EFFECT OF SEASONAL VARIATIONS ON HARDENING

Freezing temperatures necessary to secure differential injury at indicated dates in each of six seasons to the end of January at Lincoln, Nebr., are shown in Table 1. Curves derived from these data to January 11 are shown in Fig. 1. The curves all start at approximately the same level early in November. Incidentally, this level is lower, i.e., the plants were more resistant to low temperatures than greenhouse plants that had been exposed to temperatures of approximately 32° F for 3 weeks (12). The identity of some of the factors responsible for this increased hardiness, it is hoped, will be made known to some extent from the present study.

TABLE 1.—*Freezing temperatures necessary to secure differential injury at indicated dates for each of six seasons, Lincoln, Nebr.*

1930–31		1931–32		1932–33		1933–34		1934–35		1935–36	
Date	°F	Date	°F	Date	°F	Date	°F	Date	°F	Date	°F
November											
—	—	—	—	—	—	1	10	2	8	7	6
12	3	2	10	—	—	10	3	10	−1	—	—
16	0	16	7	14	1	17	−4	12	−1	19	2
29	−6	30	3	21	−3	24	−6	17	−1	25	0
December											
—	—	—	—	—	—	29	−8	22	−1	—	—
4	−8	14	−3	6	−11	13	−16	1	−6	5	−2
7	−8	—	—	9	−11	15	−16	5	−11	12	−8
19	−16	28	−4	—	—	—	—	14	−15	19	−10
—	—	—	—	—	—	—	—	17	−15	26	−11
January											
2	−20	11	−4	4	−8	10	−24	8	−15	2	−13
5	−20	25	−4	24	−8	11	−24	31	−11	8	−13
9	−20	—	—	—	—	—	—	—	—	23	−11
—	—	—	—	—	—	—	—	—	—	30	−9

It will also be noted from Fig. 1 that there is a more or less regular decrease in the "effective freezing temperature" denoting an increase in hardiness as the season progresses up until approximately the end of the experiments in January. There is, however, a marked difference in seasons and there are certain fluctuations within seasons which require explanation. In the discussion which follows, an attempt is made to relate these to the weather factors that prevailed during the study. The data presented in Table 2 summarize certain meteorological factors believed to be related to hardening. Other weather factors are mentioned in the discussion of each season.

The highest levels of hardening occurred during the seasons of 1930–31 and 1933–34. In these seasons the total hours of sunshine and radiation were greater than in any of the four other seasons, except 1932–33, when, as will be shown later, practically all leaves

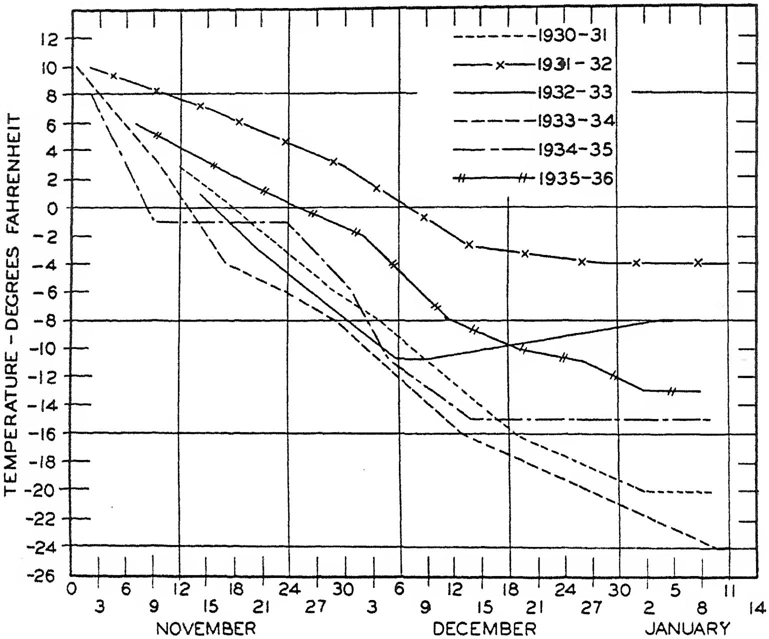

FIG. 1.—Observed progressive differences in the cold tolerance of field-grown winter wheat plants as measured by the freezing temperature required to kill 40 to 60% of Nebraska 60 wheat.

were killed on December 12. Mean temperatures were slightly above normal in consequence of rather high daily maxima. Temperatures in either season were never low enough to produce leaf injury. There were no periods of sustained snow cover. The consistent difference in hardiness between the 1930–31 curve and the one for 1933–34 seems to be a result of precipitation amounting to 3.3 inches during the period of November 17 to 20, 1930, since differences in other meterological factors were trivial.

Hardening developed least in 1931–32. In this season radiation was decidedly deficient after November 1, and rather frequent snow cover made the total radiation available to the plant even less. Precipitation was abnormally high during the entire period beginning November 9. Daily maximum temperatures averaged below those for 1930–31 and 1933–34, but minimum temperatures were higher and frosts less frequent. Only four frosts were recorded prior to November 23. During the entire period considered penetration of frost into the soil never exceeded 3 inches.

During the first half of November 1932–33 both temperatures and radiation were below normal, but during the rest of the month they were above normal. Soil moisture was more deficient than in any other season. By December 6 a rather high level of hardening for that date was noted. Lethal temperatures were recorded on December 12, but because of a light snow protection only the leaves were killed. Tests

TABLE 2.—*General record of meteorological factors believed to be related to observed hardiness differences in field-grown winter wheats, Lincoln, Nebr.*

Date	Temperature, of					Days with minimum of 32° F or below	Radiation		Precipitation, inches	
	Av. daily maximum	Av. daily minimum	Mean	Absolute maximum	Absolute minimum		Daily average, gram calories	Total sunshine, Hours	Total	Snow
1930–31:										
Nov.	55.0	33.8	44.4	71	15	13	235	233	3.40	1.0
Dec.	39.6	24.1	31.8	64	14	28	156	152	0.12	0.1
Jan.	44.6	23.4	34.0	66	2	28	215	206	0.19	1.9
1931–32:										
Nov.	52.9	34.6	43.7	80	20	12	173	136	5.60	4.2
Dec.	43.6	30.4	37.0	57	18	18	129	125	2.26	6.6
Jan.	27.8	12.6	20.2	42	− 9	31	189	129	1.92	14.5
1932–33:										
Nov.	48.5	27.0	37.8	67	8	22	216	136	0.04	0.1
Dec.	32.8	14.8	23.8	63	−14	29	185	158	0.81	6.8
Jan.	47.5	25.8	36.6	60	8	27	204	181	0.37	0.2
1933–34:										
Nov.	55.0	31.0	43.0	80	19	16	230	214	0.60	Trace
Dec.	43.2	22.5	32.8	70	− 4	24	167	165	1.05	0.5
Jan.	41.6	21.7	31.6	68	1	29	180	163	0.25	2.1
1934–35:										
Nov.	52.8	35.9	44.4	77	23	10	183	153	2.26	0.2
Dec.	33.8	19.3	26.6	47	− 2	31	150	141	0.44	4.9
Jan.	36.2	17.8	27.0	58	− 9	28	180	158	0.30	0.7
1935–36:										
Nov.	43.8	30.1	37.0	66	20	20	141	113	1.87	0.4
Dec.	37.1	22.1	29.6	56	0	27	131	126	0.30	1.8
Jan.	22.9	5.2	14.0	47	−19	31	186	152	1.64	19.3

in early January showed less hardiness than in early December. Radiation during December was exceptionally high and temperatures after the middle of the month were about average for that period. Some new growth was evident at the time of the early January tests. This new growth following severe defoliation, though not great, seems pertinent. Dexter (3) has shown loss of hardiness on production of new leaves after defoliation of plants hardened by low temperature.

The hardening trend during the 1934–35 season was the most variable of any season. High radiation and maximum temperature prior to and during the first week of November, tempered by several frosts after October 28, appeared to induce rapid hardening during the early part of the season. On the other hand, rain, low radiation, high temperatures, and absence of frosts combined to arrest hardening development completely during the period of November 10 to 22. For a 5-day period, beginning November 15, minimum temperatures did not fall below 43° F, and on one day the range was only 54° to 60°. After the November 22 test there was a very rapid acceleration in rate of hardening. Progressively lowering temperatures with small

daily variations and a conspicuous deficiency in radiation accompanied it. Beginning on November 27, and continuing for more than 5 weeks, frosts occurred each night. From November 28 until December 13 the maximum temperature did not exceed 35° F. This period of sustained low temperatures came at an unusually early date. During the first 3 weeks hardiness increased rapidly, but thereafter there was no increase despite persistence of cold weather until January. The authors (11) have shown that sustained low temperatures are effective for increasing hardiness over a period of only 3 weeks.

Conspicuously deficient radiation, frequent rainfall, and rather low temperatures were associated with the trends in hardiness during the early part of 1935–36. This season differed from 1931–32 in that the temperatures and precipitation were consistently lower. Effective radiation was apparently very similar because of less snow. Persistently low temperatures after the middle of December forced dormancy and resulted in progressively greater hardiness in each test over a 3-week period thereafter.

As previously mentioned, occasional tests were made in late January and later. These tests are mentioned here to support the belief that maximum development of hardiness was reached on or before January 11 in each season. Thus for the seasons 1934–35 and 1935–36, as shown in Table 1, tests late in January indicated that a decrease in hardiness had taken place. In the 1932–33 season, the maximum degree of hardiness was reached in December after which there was a decrease. Although not shown in Table 1, a freezing test was made February 8, 1932, which showed there had been a decline in hardiness as compared with the last preceding test made January 25. During 1930–31 no trials were made after January 9, and it is of course possible that the maximum degree of hardiness was not recorded that season. In 1933–34 there were no freezing tests between January 11 and March 9, during which period the effective freezing temperature changed from −24° to 2° F. Enough other tests were conducted during the late winter period of three of the seasons to confirm this 1934 trend and suggest that loss of hardiness under field conditions is continuous but variable in rate once it begins. A more complete record of progressive annual reductions in hardiness might have provided an interesting adjunct to the recent studies of Laude (6) on the transition from dormancy to active growth.

The hardening influence of low temperatures has long been recognized. Under field conditions this reaction does not seem to occur until both day and night temperatures remain too low for growth for several successive days. Such a change was readily recognized in all seasons except 1931–32 when very abnormal snow cover, temperature, and soil moisture conditions prevailed. Hardening from low temperatures may be initiated early, as in 1934–35, when sustained low temperatures began in late November or late, as in 1933–34, when low temperatures were not encountered until late December. In any case the resultant level of hardening seems to depend primarily upon the character of the weather preceding the cold period. Thus, in 1934–35 early incidence of sustained low temperatures probably found the plants less developed with respect to accumulation of organic reserves

than plants allowed a longer growing period the previous season. Similarly, in comparatively cold seasons, such as 1932–33 and 1935–36, when maximum hardiness would be expected if low temperatures are all important, actual hardening was relatively slight. Dexter (2) has pointed out that development and maintenance of a high available carbohydrate supply is essential in order that the cold-temperature hardening reaction may develop efficiently.

It was not possible to associate any increase in rate of hardening with differences in night temperature within the range of 10° to 35° F. High night temperatures appeared to arrest hardening, however, as shown during the period from November 10 to 22, 1934. This suggests that freezing temperatures at night, prior to the low temperature hardening reaction, may be important chiefly in restraining respiration during the long nights.

Recession in hardiness from the seasonal maximum may be abrupt under the influence of temperatures high enough to promote growth, as in 1932–33; or it may be delayed by sustained cold weather, as in 1934–35. Salmon (8) noted rapid loss of hardiness in cold-hardened plants when exposed to greenhouse temperatures.

High temperatures within the range usually observed in the field when acting in conjunction with high radiation exert a very favorable influence in preparing the plant for low-temperature hardening, as shown in 1930–31 and 1933–34. From November 1 to December 10, 1933, temperatures and radiation were at a 6-year maximum. During this 40-day period, temperatures of 32° F or lower were recorded only 22 times, and the lowest temperature was 15°. On the other hand, maximum temperatures exceeded 35° F on every day, and only on 9 of the 40 days were they below 45°. This, then, was a sustained period favorable for growth and assimilation, and not one of dormancy induced by low temperatures. Nevertheless, hardiness tests made December 13 to 15, 1933, showed greater hardening than resulted from all hardening influences (including sustained low temperatures) during any part of four other seasons. This was not the 1933–34 seasonal maximum, however, for sustained low temperatures thereafter resulted in further hardening, as indicated by the data from the freezing experiments of January 10 and 11, 1934.

The influence of day-length is perhaps the least apparent of the four climatic variables considered. The general progression toward maximum hardiness coincident with the period of shortest day-length is quite apparent in Fig. 1. Furthermore, this progression proceeded without decline of hardiness in spite of variable weather, until sustained low temperatures produced practical dormancy. It should also be noted that high radiation and temperatures while the days were becoming shorter, and before exposure to sustained low temperatures during 1930–31 and 1933–34, were perhaps an important factor in securing a high degree of hardening in those seasons. Conditions favorable to growth after sustained low-temperature hardening and in association with increasing day-lengths, however, seem to accelerate the loss of hardiness.

Hardening developed least during the excessively wet season of 1931–32. On the other hand, drought in 1932–33 probably contributed

to the high level of hardening noted on December 6 of that season. Snow cover may act to restrict hardening development if persistent as in 1931–32, or to insulate against low temperatures as in 1932–33 and 1935–36.

EFFECT OF REDUCED RADIATION ON HARDENING

It seemed desirable to verify the evidence for the relation of radiation to hardening by some special experiments designed for this purpose. Such experiments are reported in Table 3 in which the hardiness of normal field plants is compared with that of plants grown adjacent to them under a window screen cover. The experiments were conducted for 2 years. In each of them a significant reduction in cold resistance occurred as a result of growing under the screen.

TABLE 3.—*Comparative cold resistance of wheat plants grown in flats in the open and under a window screen as determined by exposure to controlled low temperature at successive dates.*

Treatment	Percentage of plants surviving								
	1934–35					1935–36			
	No. of tests on each date	Nov. 12	Dec. 1	Jan. 8	Average	No. of tests on each date	Nov. 19	Dec. 12	Average
No cover.....	2	35	64	70	56	4	45	56	51
Covered with screen.....	2	13	57	59	43	4	38	50	44

Table 4 presents results from a study in which wheat plants growing in flats in the field were covered with inverted empty flats for one or two consecutive daylight periods at intermittent dates. Each percentage survival figure given is an average of duplicate tests with eight varieties of wheat on each date. The experiments were conducted in 1935-36. The plants were covered only on clear days following at least one clear day and when temperatures were neither abnormally high nor low. While no measurements were made, it seems certain that the light leaking through the cracks in the inverted flats was at least equal to the radiation received on cloudy days. The differential cumulative treatments were applied over only a 33-day period, in October and November. The effects persisted for the duration of the experiment, however, being especially evident in the plants that received the least total radiation. Since other factors in the environment of these experiments were comparable it must be concluded that radiation is an important factor in field hardening.

DISCUSSION

Three winterhardiness stages under field conditions may be recognized from this work. The first embraces a period of accumulating organic reserves during which high radiation, high day temperatures,

TABLE 4.—*Comparative cold resistance of field-grown wheat plants covered for 1 and 2 clear-day periods as determined by exposure to controlled low temperatures at successive dates during 1935–36.*

Cumulative treatments	Percentage of plants surviving when frozen on							Percentage of total radiation during the period Oct. 28 to Nov. 30 available to plants frozen Dec. 5 to Jan. 22*
	November		December		January		Average	
	8	22	5	19	2	22		
No cover (continuous)	23	42	41	61	45	67	47	100
Covered (for 1 day periods) on Oct. 28, Nov. 5, Nov. 12, and Nov. 29	23	36	45	60	39	63	44	81
Covered (for 2 day periods) on Oct. 28 and 29, Nov. 5 and 6, 12 and 13, 29 and 30	13	21	38	43	34	46	33	67

*Assumes total darkness from cover.

scanty precipitation, and shortening day-lengths appear to be important. Normally, this influence is terminated in late December at Lincoln, Nebr. The second period is one of near dormancy induced by sustained low temperatures. Under this influence hardening seems always to reach its seasonal maximum in about 3 weeks. The third period is one of declining hardiness and progress toward active growth. This influence generally is first evident in late January. These three winterhardiness phases always occurred in the named sequence and only once during the season. Rate of development or recession varied greatly, depending on the weather.

It is apparent that field-hardening development is dependent upon a number of different and exceedingly variable climatic factors. This should be recognized in the design and interpretation of hardiness tests. More precise information on the nature and practical importance of weather hardening elements should be sought. The possible application of experiments such as this to a crop reporting service might well be considered.

SUMMARY

The observed seasonal progression and annual variations in the cold resistance of field-grown winter wheats during a 6-year period at Lincoln, Nebr., together with associated variations in the environment, were utilized in a study of the more obvious weather factors contributing to field hardening.

Two apparently distinct hardening stages were recognized in this work. During November and early December high daily temperature

maxima in conjunction with high radiation appeared to be most conducive to hardening. High temperatures with low radiation or high radiation with low temperatures were least effective. High temperatures and radiation were effective only in increasing hardening under the influence of shortening days, however. Rather xeric conditions also appeared to favor hardening. This suggests that maximum hardening at this period results from a radiation-temperature balance reacting with day-length and drought influences to give maximum accumulation of organic reserves.

Subsequent exposure to sustained low temperatures resulted in further progressive increases in hardiness for about 3 weeks. This low-temperature hardening reaction seemed always to effect maximum hardening for the season, the actual level apparently being determined by the efficiency and duration of the preceding growth-hardening stage.

Controlled experiments showing a reduction in hardiness under the influence of reduced light intensity are reported.

LITERATURE CITED

1. Akerman, A. Iakttagelser rörande höstsädens övervintring vintern 1921–1922. Sveriges Utsädesför. Tidskr., 32:252–266. 1922.
2. Dexter, S. T. Effect of several environmental factors on the hardening of plants. Plant Physiol., 8:123–139. 1933.
3. ———, Decreasing hardiness of winter wheat in relation to photosynthesis, defoliation, and winter injury. Plant Physiol., 8:297–304. 1933.
4. Gruentuch, R. A contribution to the question of hardening of winter cereals. Bul. Appl. Bot. and Plant Breeding III, 6:145–152. 1935. [Russian with English summary.]
5. Hill, D. D., and Salmon, S. C. The resistance of certain varieties of winter wheat to artificially produced low temperatures. Jour. Agr. Res., 35:933–937. 1927.
6. Laude, H. H. Cold resistance of winter wheat, rye, barley, and oats in transition from dormancy to active growth. Jour. Agr. Res., 54:899–917. 1937.
7. Newton, R. Collodial properties of winter wheat plants in relation to frost resistance. Jour. Agr. Sci., 14:178–191. 1924.
8. Salmon, S. C. Resistance of varieties of winter wheat and rye to low temperature in relation to winter-hardiness and adaptation. Kans. Agr. Exp. Sta. Tech. Bul. 35. 1933.
9. Saprygina, E. S. Frost resistance of spring wheats. Compt. Rend. (Doklady) Acad. Sci. U. R. S. S., 3:325–328. 1935.
10. Scarth, G. W., and Levitt, J. The frost hardening mechanisms of plant cells. Plant Physiol., 12:51–78. 1937.
11. Suneson, C. A., and Peltier, G. L. Cold resistance adjustments of field hardened winter wheats as determined by artificial freezing. Jour. Amer. Soc. Agron., 26:50–58. 1934.
12. ———, ———. Effect of stage of seedling development upon the cold resistance of winter wheats. Jour. Amer. Soc. Agron., 26:687–692. 1934.
13. ———, ———. Effect of defoliation upon the cold resistance of winter wheat. Jour. Amer. Soc. Agron., 28:807–809. 1936.
14. Tumanov, I. I. The hardening of winter plants to low temperatures. Bul. Appl. Bot. and Plant Breeding, 25(3):69–109. 1931. [Russian with English summary.]
15. ———, Borodina, I. N., and Oleinikova, I. V. The role of snow cover in the wintering of crops. Bul. Appl. Bot. and Plant Breeding III, 6:3–58. 1935. [Russian with English summary.]
16. Tysdal, H. M. Influence of light, temperature, and soil moisture on the hardening process in alfalfa. Jour. Agr. Res., 46:483–515. 1933.
17. Worzella, W. W. Inheritance of cold resistance in winter wheat, with preliminary studies on the technique of artificial freezing. Jour. Agr. Res., 50:625–635. 1935.

THE RESPONSE OF SOYBEANS TO SOURCES OF NITROGEN IN THE FIELD[1]

W. B. ANDREWS[2]

IN inoculation tests with legumes in the field and in the greenhouse it is often desirable to compare yields with those obtained with combined nitrogen. Data on the response of soybeans to different sources of nitrogen will, therefore, be valuable in setting up tests of this kind. In a previous paper (2)[3] data were reported which show that 600 pounds of ammonium sulfate per acre did not reduce the amount of nitrogen fixed by soybean nodule bacteria.

Caldwell and Richardson (5) found that ammonium sulfate is not toxic to red clover when high quantities are added to the soil. The fact that legumes in mixtures containing grasses often do not do as well when combined nitrogen is applied has been interpreted differently by different investigators (2). Emphasis is placed upon the preference of legumes for nitrogen obtained through nodule bacteria on the one hand and the competition induced by the increased growth of grasses where combined nitrogen is applied, on the other hand.

Umbreit and Fred (14) concluded that, "Under conditions which result in a balanced carbohydrate-nitrogen relation in the soybean plant free nitrogen is the preferred form of nitrogen". A balanced carbohydrate-nitrogen relation "normally occurs under adequate sunlight of moderate intensity and in the presence of sufficient moisture and carbon dioxide". They concluded that, "If an excessive carbohydrate-nitrogen relation develops in the plants, the growth is favored by the presence of combined nitrogen".

Nitrate nitrogen has usually reduced the number of nodules and nitrogen fixation by legumes (6, 7, 8, 11, 12, 13), while small amounts of nitrates and ammonium sulfate have been reported to stimulate nodule production.

Allison and Ludwig (1) reviewed the literature on nodule reduction and decreased nitrogen fixation due to the application of high quantities of nitrogen, and from the data presented concluded that nitrogen reduced the root and nodule development through a reduction in the carbohydrate supply; whereas, Hopkins and Fred (8) and other workers from Wisconsin (6, 10, 14) placed emphasis on the relation between the carbohydrate supply and the functioning of the nodule bacteria. Andrews and Gieger (3) reported data on greenhouse work which show that nitrate of soda reduced the yield and nitrogen fixation by Austrian winter peas in the greenhouse.

Most of the work reported on the effect of nitrogenous fertilizers on legumes has been conducted in the greenhouse. The data reported in this paper were obtained in the field under natural growing conditions, and as a result, should be valuable in a study of the response of soybeans to combined nitrogen.

EXPERIMENTAL

Four sources of nitrogen were applied to soybeans in the field on Lufkin clay soil of pH 4.6 to 4.9. Three hundred pounds per acre of

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[3]Figures in parenthesis refer to "Literature Cited," p. 786.

superphosphate were applied to all plats. The limed plats received 400 pounds of dolomite per acre. The sources of nitrogen were applied at the following rates per acre: Ammonium sulfate, 600 pounds; nitrate of soda, 800 pounds; cyanamid, 571 pounds; and urea, 348 pounds. The plats consisted of one row, 3½ feet wide and 1/400 acre in size, and were replicated six times. Inoculated and uninoculated Biloxi soybean seed were planted May 17, 1937. The seed were covered lightly and the fertilizer and dolomite were put out about 2½ inches to one side of the seed, after which they were covered well. An excellent stand of soybeans was obtained and they were cultivated to keep down weeds. The soybeans were harvested in the small bean stage on September 13. Green weights were obtained for all plats, and they were converted into air-dry weights per acre. Samples for nitrogen determinations were obtained, dried, ground, and analyzed according to the methods of official agricultural chemists.

The standard error of the mean of each treatment was determined. The standard errors of the increases were calculated from paired yields.

EXPERIMENTAL RESULTS

The data on the effect of nitrogen source on the yield and nitrogen content of uninoculated and inoculated soybeans grown on limed and unlimed soil are reported in Table 1. The data are broken down to show the effects of the source of nitrogen, inoculation, and lime more plainly and are reported in Tables 2, 3, and 4.

TABLE 1.—*The effect of nitrogen source on the yield and nitrogen content of soybeans grown on limed and unlimed soil.*

Source of nitrogen	Unlimed		Limed	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
		Uninoculated		
$(NH_4)_2SO_4$	4,667±321	1.88±0.013	5,302±215	1.96±0.296
$NaNO_3$	5,407±289	2.37±0.068	4,982±817	2.31±0.196
Cyanamid	4,438±253	1.79±0.077	3,960±187	1.75±0.253
Urea	5,498±228	2.33±0.095	5,338±199	1.96±0.164
Check	3,140±341	1.29±0.119	3,378±256	1.60±0.121
		Inoculated		
$(NH_4)_2SO_4$	4,938±184	1.97±0.074	5,311±215	2.00±0.212
$NaNO_3$	5,820±243	2.28±0.101	5,740±243	2.10±0.054
Cyanamid	4,853±160	1.99±0.104	4,575±171	1.84±0.073
Urea	5,833±116	2.23±0.095	5,420±209	2.32±0.156
Check	3,653±291	1.73±0.086	3,802±397	1.63±0.063

EFFECT OF SOURCE OF NITROGEN ON YIELD AND NITROGEN CONTENT OF SOYBEANS

The yield of the soybeans receiving no nitrogen was 3,140±341, 3,378±256, 3,653±291, and 3,802±397 pounds per acre for the uninoculated unlimed, uninoculated limed, inoculated unlimed, and

TABLE 2.—*Increase in yield and nitrogen content of soybeans due to nitrogen source.*

Source of nitrogen	Unlimed		Limed	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
		Uninoculated		
$(NH_4)_2SO_4$	1,571±124	0.58±0.082	1,924±171	0.36±0.136
$NaNO_3$	2,266±236	1.07±0.143	1,686±270	0.71±0.147
Cyanamid	1,297±172	0.51±0.170	582±196	0.16±0.163
Urea	2,357±305	1.03±0.181	1,960±235	0.20±0.160
Check	3,140±341	1.29±0.119	3,378±256	1.60±0.121
		Inoculated		
$(NH_4)_2SO_4$	1,284±298	0.24±0.123	1,509±250	0.37±0.085
$NaNO_3$	2,166±267	0.54±0.073	1,977±318	0.48±0.055
Cyanamid	1,200±189	0.27±0.150	773±403	0.21±0.054
Urea	2,179±216	0.50±0.155	1,617±351	0.69±0.148
Check	3,653±291	1.73±0.086	380±397	1.63±0.063

TABLE 3.—*Increase or decrease in yield and nitrogen content of soybeans receiving nitrogen from different sources due to lime.*

Source of nitrogen	Uninoculated		Inoculated	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
$(NH_4)_2SO_4$	635±186	0.08±0.100	373±173	0.02±0.055
$NaNO_3$	-120±183	0.07±0.083	- 80±196	-0.16±0.085
Cyanamid	-478±257	0.04±0.115	-278±222	-0.15±0.107
Urea	-160±285	-0.37±0.198	-413±146	0.09±0.231
Check	238±197	0.30±0.043	149±315	-0.11±0.078

TABLE 4.—*The effect of inoculation on the increase in yield and nitrogen content of soybeans receiving nitrogen from different sources.*

Source of nitrogen	Unlimed		Limed	
	Pounds of soybeans per acre	N. %	Pounds of soybeans per acre	N. %
$(NH_4)_2SO_4$	271±225	0.10±0.070	9±152	0.04±0.096
$NaNO_3$	413±170	0.02±0.149	453±99	-0.17±0.115
Cyanamid	415±88	0.20±0.135	615±212	0.08±0.048
Urea	336±197	0.10±0.137	82±104	0.35±0.290
Check	513±241	0.44±0.173	424±202	0.03±0.159

inoculated limed soil, respectively. The corresponding nitrogen contents were 1.29±0.119, 1.60±0.121, 1.73±0.086, and 1.63±0.063%.

Nitrate of soda increased the yield of the soybeans 2,266±236, 1,686±270, 2,166±267, and 1,977±318 pounds per acre on the uninoculated unlimed, uninoculated limed, inoculated unlimed, and in-

oculated limed soil, respectively. The corresponding nitrogen contents where nitrate of soda was applied were 2.37 ± 0.068, 231 ± 0.196, 2.28 ± 0.101, and $2.10\pm0.054\%$. The corresponding increases in nitrogen content were 1.07 ± 0.143, 0.71 ± 0.147, 0.54 ± 0.073, and $0.48\pm 0.055\%$. These increases in yield and nitrogen content indicate that, under the conditions of this experiment, soybeans are able to utilize nitrate of soda efficiently.

The increases in yield where urea was used were just about the same as those for nitrate of soda. Likewise, the increases in nitrogen content due to the application of urea were about the same as those where nitrate of soda was used, except in the case of the uninoculated soybeans on the limed soil. In this case the increase in nitrogen content where nitrate of soda was applied is significantly greater than that obtained where urea was used.

With both the uninoculated and inoculated soybeans on the unlimed soil the increases in yield where ammonium sulfate and cyanamid were applied were only about two-thirds as large as those where urea and nitrate of soda were applied. The increases in nitrogen content where ammonium sulfate, and cyanamid were applied were only about half as large as where urea and nitrate of soda were applied. On the limed soil urea, nitrate of soda and ammonium sulfate made about the same increase in yield of inoculated and uninoculated soybeans and the increase produced by cyanamid was only about a third that obtained with the other sources. The increases in nitrogen content where cyanamid was applied to limed soil were 0.16 ± 0.136, and $0.21\pm0.055\%$ for uninoculated and inoculated soybeans, respectively. The addition of lime reduced the increase in yield obtained from the application of cyanamid to about half that obtained without lime. The lime added was only about two-thirds enough to neutralize the sulfate radical of the ammonium sulfate.

EFFECT OF LIME ON RESPONSE OF SOYBEANS TO SOURCES OF NITROGEN

The data in Table 3 show that lime increased slightly, but not significantly, the yield of the soybeans receiving no nitrogen on both the inoculated and uninoculated series. On the check plats lime increased the nitrogen content $0.30\pm0.045\%$. The nitrogen content of the soybeans receiving no treatment was $1.29\pm0.119\%$. Lime increased the yield of the uninoculated soybeans significantly in only one case and that was with ammonium sulfate. Lime decreased the yield of the soybeans in every case where nitrate of soda, urea, and cyanamid were applied. The decrease was significant only in the case of inoculated soybeans receiving urea. The only case where lime affected significantly the nitrogen content of the soybeans receiving nitrogen was in the uninoculated soybeans receiving urea. The nitrogen content of the latter was decreased $0.37\pm0.198\%$.

EFFECT OF INOCULATION ON RESPONSE OF SOYBEANS TO SOURCES OF NITROGEN

Without the addition of nitrogen, inoculation increased significantly the yield and nitrogen content of the soybeans on the unlimed soil

and the yield on the limed soil. The nitrogen content of the soybeans receiving inoculation on the limed soil was no greater than that of the soybeans receiving no inoculation. Inoculation did not increase the yield nor the nitrogen content significantly where ammonium sulfate and urea were applied. Inoculation increased the yield of the soybeans receiving nitrate of soda and cyanamid significantly on both the limed and the unlimed soil but had no significant affect on the nitrogen content.

RESPONSE OF STRAINS OF SOYBEAN ROOT NODULE BACTERIA TO LIME

Cowpeas had been grown on the soil on which these soybeans were grown on different years previous to the year the test was conducted. Soybeans had never been grown on this soil. Common lespedeza also volunteers in pastures on the soil type used in this experiment. When lime was added to the soil receiving no nitrogen, the nitrogen content of the soybeans was increased significantly; however, the increase in yield was not significant. Inoculation of the soybeans on the unlimed soil produced an increase in yield of 513 ± 241 pounds per acre and an increase of 0.44 ± 0.173 %in the nitrogen content. On the limed soil inoculation increased the yield of the soybeans 424 ± 202 pounds per acre but the nitrogen content was not changed. Evidently the strain of nodule bacteria applied was more efficient than the native strain on unlimed soil. These data are in harmony with those reported by Briscoe, Andrews, and Cowart (4) on the response of strains of soybean root nodule bacteria to lime.

RESPONSE OF SOYBEANS TO IONS ASSOCIATED WITH NITROGEN

Urea applied to the soil probably hydrolyzes to ammonium carbonate in a short time. The reaction is as follows: $CO(NH_2)_2 \pm 2H_2O \rightarrow (NH^4)_2CO_3$. Urea should therefore have practically the same affect on the yield and nitrogen content of soybeans as would ammonium carbonate. Since the soil is well supplied with CO_2, the results obtained with ammonium carbonate should be similar to those obtained from the addition of pure ammonia gas. In either case the soil colloids would absorb large quantities of ammonia and ammonium carbonate would exist in the soil solution for a short time at least. The application of urea to the soil for soybeans should therefore have the same influence on the yield and nitrogen content of soybeans as the application of pure ammonia.

Urea produced excellent increases in the yield and nitrogen content of soybeans. The results obtained with nitrate of soda were practically the same as those obtained with urea which indicates that the soybeans utilized the nitrate nitrogen of nitrate of soda and the amid nitrogen of urea equally well, and that there was apparently little, if any, influence exerted by the sodium of the nitrate of soda. However, the nitrogen content of the uninoculated soybeans on the unlimed soil receiving nitrate of soda was significantly greater than that of those receiving urea.

If soybeans respond to urea as if the nitrogen it contains were ammonium nitrogen, the difference between their response to urea

and to ammonium sulfate, $(NH_4)_2SO_4$, would seemingly be due to the sulfate radical. The sulfate radical reduced both the yield and the nitrogen content of the soybeans on the unlimed soil, but the harmful affects of the sulfate radical were overcome by the application of dolomite.

Cyanamid is a mixture of about 65% $CaCN_2$, about 15% $Ca(OH)_2$, and other constituents. The 571 pounds of cyanamid applied had about 46% more calcium than the dolomite which contained both calcium and magnesium. Even though the cyanamid radical produced excellent increases in yield and small increases in the nitrogen content of the soybeans, it was inferior in these respects to the ammonium and nitrate radicals for soybeans. The inferiority of the cyanamid group was increased on application of dolomite.

DISCUSSION

The work of Umbreit and Fred (14) shows that, "Under conditions which result in a balanced carbohydrate-nitrogen relation in the soybean plant free nitrogen is the preferred form of nitrogen". Under these conditions the soybean has a relatively high nitrogen content and nitrogen fixation goes on rapidly. Orcutt and Fred (10) pointed out that, "The percentage of nitrogen may be taken as a negative index of the carbohydrate level". A high nitrogen content indicates a low carbohydrate level and a low nitrogen content indicates a high carbohydrate level. Umbreit and Fred also concluded that, "Under conditions in which carbohydrate synthesis is restricted, the best development of soybeans is obtained in those plants which are furnished combined nitrogen".

Orcutt and Fred (10) concluded that an extremely high carbohydrate-nitrogen relation in the soybean plant inhibits nitrogen fixation. They obtained an extremely high carbohydrate-nitrogen relation when soybeans were grown in the sunlight in the summer. Shading brought about a change in the carbohydrate-nitrogen relation which was conducive to nitrogen fixation.

The percentage of nitrogen in the inoculated soybeans receiving no combined nitrogen was 1.63 and 1.73% on the unlimed and limed soil, respectively. On the basis of the nitrogen content indicating the carbohydrate level, this percentage of nitrogen indicates a high carbohydrate level. The high carbohydrate production is further indicated by the maximum yield produced which was nearly 3 tons per acre. In this test it is evident that the production of carbohydrates was nearly a maximum, and under these conditions nitrate of soda and urea increased the yield of the soybeans about a ton per acre. Ammonium sulfate and cyanamid were less effective than were the former two sources of nitrogen. On the unlimed soil nitrate of soda and urea increased the nitrogen content of the uninoculated soybeans more than 1%. With inoculated soybeans the increases in nitrogen content were around 0.5%. Cyanamid and ammonium sulphate were less effective in increasing the nitrogen content than were nitrate of soda and urea.

The data presented by the author in a previous paper (2) show that ammonium sulfate was very effective in increasing the yield and had only a small effect on the nitrogen content. The nitrogen content and yield of these soybeans indicate that carbohydrate production was at a relatively low level in this test.

An examination of the weather records for the two years in which these tests were conducted reveals a difference in rainfall during the growing season. The soybeans were planted and harvested at about the same time on each year. In 1933 the yield and nitrogen content of inoculated soybeans on limed soil was 2,013 pounds per acre and $2.20 \pm 0.021\%$ nitrogen where 75 pounds of ammonium sulfate were applied per acre. The data were not reported for the no-nitrogen treatment. The 75 pounds per acre of sulfate of ammonia increased the yield a small amount and probably had only a small effect on the nitrogen content. The season was very dry with only 0.84 inch of rainfall in June. Big rains fell on July 2, 9, and 10, with only occasional showers until August 29. In 1937 the yield and nitrogen content of the inoculated soybeans on limed soil without nitrogen treatment was 3,802 pounds per acre and $1.63 \pm 0.063\%$ nitrogen. In 1937 the rainfall was sufficient and well distributed. The yield and nitrogen content of the soybeans these two years indicate that carbohydrate production was very low during 1933 and that it approached a maximum during 1937. The high production of carbohydrates during 1937 is therefore attributed to the favorable growing season.

The energy requirement in nitrogen fixation was calculated from the data presented in the previous paper (2) to be about 50 pounds of soybean hay for 1 pound of nitrogen. The data presented in this paper could not be used to calculate the energy requirement of soybeans. Evidently, the energy requirement in nitrogen fixation can be calculated only from data which are obtained under conditions of limited carbohydrate production.

SUMMARY AND CONCLUSIONS

The response of soybeans to sources of nitrogen was determined in the field with inoculated and uninoculated Biloxi soybeans on limed and unlimed soil. Yields and nitrogen determinations were made. The yields and nitrogen content data indicate that the production of carbohydrates was at a high level. The data may be summarized as follows:

1. Nitrate of soda and urea were superior to ammonium sulfate and cyanamid in the production of soybeans and increased the nitrogen content of the soybeans on unlimed soil.
2. On limed soil ammonium sulfate was almost equal to urea and nitrate of soda as a source of nitrogen for soybeans.
3. Cyanamid was decidedly inferior to nitrate of soda, urea, and ammonium sulfate as a source of nitrogen for soybeans on limed soil.
4. Lime increased the yield of soybeans where ammonium sulfate was applied and decreased it where urea, cyanamid, and nitrate of soda were used.

5. Inoculation produced significant increases in yield of soybeans where nitrate of soda and cyanamid were used but did not where ammonium sulfate and urea were used.

6. Inoculation did not increase the nitrogen content of soybeans significantly where any source of nitrogen was used.

7. The native strain of soybean root nodule bacteria was in greater need of lime on the unlimed soil than the strain which was added.

8. The strain of soybean root nodule bacteria added was better suited to the soil conditions as they existed than was the native strain.

9. Carbohydrate production was much higher in a year of good distribution of rainfall than in a dry year, and conversely, the nitrogen content was much higher in the dry year when the soybeans obtained their nitrogen primarily from the soil and the root nodules.

10. On unlimed soil nitrate and amid nitrogen were superior to cyanamid for soybeans, and the sulfate radical of ammonium sulfate reduced the yield. Where dolomite was added, nitrate, amid, and ammonium nitrogen were superior to cyanamid nitrogen for soybeans.

LITERATURE CITED

1. Allison, Franklin E., and Ludwig, C. A. The cause of decreased nodule formation on legumes supplied with abundant combined nitrogen. Soil Science, 37:431–443. 1934.
2. Andrews, W. B. Effect of ammonium sulphate on the response of soybeans to lime and artificial inoculation and the energy requirements of soybean nodule bacteria. Jour. Amer. Soc. Agron., 29:681–689. 1937.
3. ———, and Geiger, Marvin. The effect of the association of rye and Austrian winter peas and of nitrate of soda on nitrogen fixation. Jour. Amer. Soc. Agron., 30:529–536. 1938.
4. Briscoe, Charles F., Andrews, W. B., and Cowart, Roland. Effect of strains of nodule bacteria and lime on the response of soybeans to artificial inoculation. Jour. Amer. Soc. Agron., 30:711–719. 1938.
5. Caldwell, J., and Richardson, H. L. The growth of clover in the presence of ammonium sulphate. Jour. Agr. Sci., 26:263–267. 1936.
6. Fred, E. B., and Wilson, P. W. On photosynthesis and free nitrogen assimulation by plants. Proc. Nat. Acad. Sci. Wash., 20:403–409. 1934.
7. Giobel, G. The relation of soil nitrogen to nodule development and fixation of nitrogen by certain legumes. N. J. Agr. Exp. Sta. Bul. 436. 1936.
8. Hopkins, E. W., and Fred, E. B. Influence of various nitrogenous compounds and mannitol on nodule formation by clover. Plant Phys., 8:141–155. 1933.
9. Ohkawara, S. Influence of nitrates and sulphates on the nodule bacteria and nodule formation of Genge, Lupine and Serradella. Proc. First Int. Congress Soil Sci., 3:172–182. 1928.
10. Orcutt, Fred S., and Fred, E. B. Light intensity as an inhibiting factor in the fixation of atmospheric nitrogen by Manchu soybeans. Jour. Amer. Soc. Agron., 27:550–558. 1935.
11. Prucha, M. J. Physiological studies of Bacillus Radicicola of Canada field pea. Cornell Univ. Agr., Exp. Sta. Mem. 5. 1915.
12. Stroud, W. H. The relation of nitrates to nodule production. Soil Science, 10:343. 1920.
13. Thornton, H. G., and Nicol, Hugh. Reduction of nodule numbers and growth, produced by the addition of sodium nitrate to Lucerne in sand cultures. Jour. Agr. Sci., 26:173–188. 1936.
14. Umbreit, Wayne W., and Fred, E. B. The comparative efficiency of free and combined nitrogen for the nutrition of the soybean. Jour. Amer. Soc. Agron., 28:548–555. 1936.

NOTE

A SIMPLE HEAD THRESHER

IN breeding work with small grains some method of threshing individual heads and panicles is indispensable. It is the purpose of this paper to describe the construction and operation of a cheap and efficient device designed for single-head threshing.

A motor-operated machine similar to that described by Kemp[1] was formerly used at the Georgia Experiment Station, but experience has shown that the grille type of thresher herein described is more efficient than cylinder types. Peto[2] has described a device for single-head threshing and reports excellent results from its use but the construction and operation of the apparatus described requires laboratory facilities and some little skill in metal work.

The thresher illustrated in Fig. 1 is of very simple construction and may be made from scrap materials. The metal seed-pan was made for use with the motor-driven cylinder thresher formerly used for threshing single heads, and the grille was constructed to fit the pan. A square cornered pie pan with sloping sides about 1 inch deep will serve for the seed-pan.

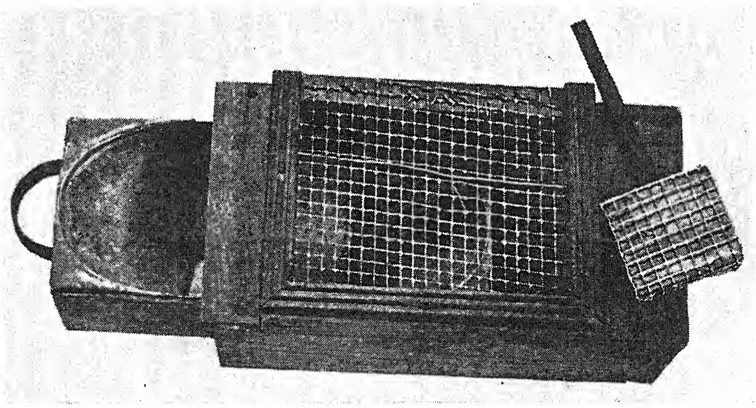

FIG. 1.—A head thresher. Wood construction is of 1-inch dressed material. The metal seed-pan (partly withdrawn) is scoop-shaped in its outline to facilitate the blowing out of chaff and sacking of seeds.

The grille is a section of galvanized hardware cloth of 3/8-inch mesh, mounted in a frame over the seed-pan, and three edges are covered with thin moulding. The scrubbing block is about 2½ by 2½ inches, and should be covered with the same type of wire cloth as that used for the grille. Reference to Fig. 1 will probably make further description unnecessary.

In operation, a spike or panicle of the grains is held on the wire screen by holding the culm in the left hand, while by a scrubbing motion of the block held in the right hand, the seeds and glumes from

[1]KEMP, H. J. Mechanical aids to crop experiments. Sci. Agr., 15:488–506, 1935.
[2]PETO, F. H. A simple method of head threshing. Sci. Agr., 15:825–826. 1935.

the spike or panicle are rubbed off the rachis and fall into the seed-pan. The seed-pan is then removed from the grille-box, and by a little judicious shaking and blowing, the chaff may be blown out, leaving the seeds to be poured into an envelope. Description of the actual operation of threshing is difficult, but after a few moment's practice the proper method will readily suggest itself to any operator.

The chief advantage of this device is in the fact that it will handle any of the small grains, sorghum, grain sorghum, and clovers, and is very efficient for preparing inoculum of bunt and oat smuts. The entire outfit may be conveniently sterilized in an autoclave. Timing tests show that 400 wheat heads may be threshed with this device in an hour and sealed in envelopes. This test does not account for time required for labeling. Experience has proved that this is by far the most efficient method of single-head threshing yet tried at the Georgia Station.—S. J. HADDEN, *Georgia Agricultural Experiment Station, Experiment, Georgia.*

AGRONOMIC AFFAIRS

FERTILIZER RECOMMENDATIONS FOR 1939

RECOMMENDATIONS for 1939 made by the Tobacco Research Committee made up of representatives for Virginia, North and South Carolina, Georgia, and Florida and the U. S. Department of Agriculture, are now available from the Chairman of the Committee, C. B. Williams, Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C.

NEWS ITEMS

ON JULY 1, P. H. DeHart, instructor in Agronomy, Virginia Polytechnic Institute, resigned to accept a position with the agricultural Adjustment Administration with headquarters in Blacksburg. Mr. M. S. Kipps formerly in charge of the experimental plat work in Blacksburg has been assigned to full time teaching and will assume the duties formerly carried by Mr. DeHart. Mr. Ed Shulkcum who has been working as a soil survey field man in Virginia since 1930 has accepted the position as Superintendent of experimental plat work at Blacksburg. Mr. E. M. Dunton, Assistant Agronomist, in charge of testing different sources of phosphates in Virginia has tendered his resignation effective September 1, to accept a fellowship in Cornell University where he expects to take graduate work leading towards a Ph. D. degree in soils. Mr. R. E. O'Brien, at present Assistant Agronomist at this station in charge of pasture investigations, will be transferred to assume duties formerly carried by Mr. Dunton. Dr. A. L. Grizzard, who has been Assistant Agronomist with the National Fertilizer Association at Washington since leaving this station in January 1937 will return to Blacksburg, as Associate Agronomist, in charge of pasture investigations and other experiment station duties.

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REPLACEMENT OF CALCIUM IN SOILS BY SODIUM FROM SYNTHETIC IRRIGATION WATER[1]

G. S. FRAPS AND J. F. FUDGE[2]

IRRIGATION waters in dry sections of the country frequently contain soluble salts. The formation of saline or alkali soils through the action of irrigation waters containing sodium salts is due to evaporation of the water without adequate leaching to prevent the accumulation of salts. The exchange of the calcium in the soil by sodium in the irrigation waters may cause the soil to run together so as to decrease percolation and increase the possibility of the accumulation of salts.

Kelley (2)[3] has pointed out that the action of the irrigation water upon the soil will depend upon the relative proportions of sodium and calcium in the water, and that wherever calcium is an important constituent of the accumulated soluble salts, the base exchange material is not greatly affected by the sodium salts, even though the concentration of soluble sodium salts be extremely high. Irrigation waters may contain sodium and calcium in the form of bicarbonates, chlorides, and sulfates in considerable quantities. Nitrates and magnesium salts are usually present in very small amounts, except in very exceptional cases. The experiments in this paper were undertaken to secure further information concerning the effect of different concentrations of sodium and calcium salts in irrigation waters upon the exchangeable calcium in the soil.

EXPERIMENTAL DATA

The differential energy of absorption of different ions has been well established. Gedroiz, in his pioneer work on base exchange showed that sodium is rather easily replaced by calcium, whereas calcium is by no means so easily replaced by sodium. This difference between cations has also been emphasized by Kelley (1). In the first experiments conducted, therefore, the relative energy of absorption or replacing activity of calcium and sodium were estimated by determining the proportions in which they replace hydrogen in the hydrogen-

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Published with the approval of the Director. Received for publication June 1, 1938.

[2]Chief, Division of Chemistry, and Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 796.

saturated exchange complex of a soil. Fifty grams of soil were shaken with 200 cc of N hydrochloric acid for 15 minutes. The soil was filtered off, leached with 200 cc of 0.2 N hydrochloric acid, and washed free of chlorides. The soil was again shaken with 200 cc of solution made up so that the total M.E. of salt in the solution equaled the exchange capacity of the 50 grams of soil. One-half of the salt was calcium chloride and the other half was sodium chloride. After shaking for 1 hour, the filtrate was analyzed for calcium and hydrogen ions which had been replaced from the exchange complex by sodium and calcium. The difference between the hydrogen ions found and decrease in calcium in solution was assumed to equal the quantity of sodium absorbed by the soil. Jenny (3) has proposed a similar method for measuring the relative absorbability of different ions.

The data secured are given in Table 1. Basicity is the quantity of acid, expressed as percentage of calcium carbonate, which was neutralized by the soil in digestion with 0.2 N nitric acid. From the data in Table 1, the relative exchange or replacing activities of calcium and sodium were estimated. Calcium and sodium together replaced about 20% of the total exchangeable hydrogen in the exchange complex. Of this quantity, calcium represented about 75% and sodium about 25%. The calcium was therefore about three times as active as the sodium in replacing the hydrogen. Even though the actual numerical value of the proportion might vary with different relative concentrations of sodium and calcium in solution, the data presented show that the energy of absorption or the replacing activity of calcium is several times as great as that of sodium.

TABLE 1.—*Relative replacement of hydrogen in an acid soil by calcium and sodium from solution.*

	Soil No. 12572, Crawford loam	Soil No. 18542, Wilson clay	Soil No. 7147, San Antonio silty clay loam	Soil No. 29427, Crockett clay loam	Soil No. 26079, Bell clay
Basicity, %	3.18	1.85	4.72	1.26	2.61
Total exchange capacity, M. E.	44.21	46.76	44.04	28.85	46.36
Calcium absorbed from solution M. E.	6.24	6.88	3.80	4.60	7.48
Hydrogen in solution, M. E.	8.38	9.34	5.20	6.18	9.98
Hydrogen replaced in percentage of exchange capacity	19.0	20.0	11.8	21.4	21.5
Calcium absorbed in percentage of hydrogen replaced	74.5	73.6	73.1	74.4	74.9
Calcium absorbed in percentage of sodium absorbed	292	279	272	291	298
Sodium absorbed in percentage of hydrogen replaced	25.5	26.4	26.9	25.6	25.1

The replacement of calcium from the exchange complex of the soil by sodium in solutions of sodium chloride, sodium chloride with calcium chloride and sodium bicarbonate was next studied. Fifty grams

of soil were shaken 1 hour with 200 cc of water or of salt solution, filtered, and calcium determined in the filtrate. The quantity of calcium in solution with water was subtracted from that in the salt solution to give the net quantity of calcium replaced by the sodium. These data are given in Table 2. The quantity of calcium exchanged by a given salt solution did not increase regularly with increase in total exchange capacity of the soil but was largely determined by the character of the individual soil. For example, soils Nos. 18542 and 26079 have similar exchange capacities, but the quantities of calcium replaced from soil No. 26079 by sodium chloride were almost twice those replaced from soil No. 18542. The average quantity of calcium replaced by the various sodium chloride solutions was equivalent to

TABLE 2.—*Net increase (M. E.) in calcium content of solutions containing sodium chloride or sodium bicarbonate.*

Laboratory No.	Total exchange capacity 50 grams soil, M.E.	Salt used	Quantity (M. E.) of sodium salt used			
			2.5	5.0	7.5	10.0
29427, Crockett clay loam	14.4	NaCl	0.73	1.20	1.63	2.14
		NaCl+5 $CaCl_2$	0.16	0.26	0.62	0.86
20196, Abilene silty clay loam	14.8	NaCl	0.85	1.41	1.71	2.51
		NaCl+5 $CaCl_2$	0.45	0.78	0.98	1.15
		$NaHCO_3$	0.18	0.27	0.16	0.04
12584, Durant loam	14.9	NaCl	0.92	1.72	2.34	2.89
12582, Ellis clay	16.3	NaCl	0.76	1.22	1.72	2.40
		NaCl+5 $CaCl_2$	0.53	0.95	1.30	1.52
26075, Irving clay	18.4	NaCl	1.10	1.84	2.54	3.39
		NaCl+5 $CaCl_2$	0.55	1.13	1.34	1.64
		$NaHCO_3$	0.15	0.36	0.38	0.55
7147, San Antonio silty clay loam	22.0	NaCl	0.76	1.23	1.77	2.28
		NaCl+5 $CaCl_2$	0.50	0.93	1.22	1.43
12572, Crawford loam	22.1	NaCl	1.20	1.98	2.81	3.78
21067, Trinity clay	22.9	NaCl	0.81	1.37	1.96	2.75
		NaCl+5 $CaCl_2$	0.56	1.13	1.56	1.85
26079, Bell clay	23.2	NaCl	1.20	2.09	2.99	3.78
		NaCl+5 $CaCl_2$	0.38	1.04	1.42	1.54
		$NaHCO_3$	0.44	0.42	0.26	0.21
18542, Wilson clay	23.4	NaCl	0.53	1.05	1.51	2.02
		NaCl+5 $CaCl_2$	0.60	1.12	1.53	1.91
26095, Houston black clay	25.7	NaCl	1.26	2.21	3.14	4.12
		NaCl+5 $CaCl_2$	0.67	1.24	1.62	1.87
		$NaHCO_3$	0.40	0.30	0.03	0.03
Calcium replaced as percentage of sodium salt		NaCl	36	32	30	30
		NaCl+5 $CaCl_2$	19	19	17	15

about 30% of the salt in the original solutions. The addition of calcium chloride to the sodium chloride solutions reduced the quantity of calcium replaced by the sodium by about one-half, the decrease again varying with the individual soils. Net increases in the quantity of calcium in the filtrates after treatment of the soil with sodium bicarbonate solutions were quite small, and, in general, decreased with an increase in the concentration of the solutions. The sodium in the bicarbonate probably effects the exchange of some calcium, but this is precipitated as the carbonate and not removed from the soil.

Solutions containing both sodium chloride and sodium bicarbonate in different ratios gave net increases in calcium as shown in Table 3. The presence of the 1 M.E. of bicarbonate in the solution reduced the quantity of calcium in solution 52%, and 2 M.E. reduced it 44% when compared with the solution containing 5 M.E. of chloride alone. However, an increase in either sodium chloride or sodium bicarbonate resulted in a slight increase in the quantity of calcium in solution.

TABLE 3.—*Net increase (M. E.) in calcium content of solutions containing sodium chloride and sodium carbonate.*

Laboratory No.	Sodium chloride, M. E.	2	5	2	5	5
	Sodium bicarbonate, M.E.	2	2	1	1	0
20196	Abilene silty clay loam	0.36	0.64	0.30	0.52	1.41
26075	Irving clay	0.92	1.35	0.83	1.00	1.84
26079	Bell clay	0.87	1.42	0.72	1.18	2.09
26095	Houston black clay	0.88	1.34	0.75	0.99	2.21

The work with sodium chloride and sodium bicarbonate emphasizes the importance of the distinction between saline waters and those which are truly alkaline, containing relatively high concentrations of carbonates. When soils are irrigated with saline waters in which the sodium is combined in neutral salts, such as the chloride or the sulfate, the calcium remains in solution and equilibrium between the sodium in the irrigating water and the exchanged calcium is comparatively rapidly established and exchange of the calcium is reduced. With alkaline waters which contain carbonates, however, the calcium is precipitated, equilibrium is much more slowly established, and the sodium replaces a great deal more of the exchangeable calcium of the soil. This point has also been emphasized by Kelley (2).

In the preceding experiments, the soil was treated but once; whereas when irrigated, the soil is treated repeatedly with water containing the salts. The question arises as to whether or not the soil continues to lose calcium or if the soil finally reaches approximate equilibrium with the particular solution. In order to study this point, a number of soils were treated repeatedly with solutions similar to those used in the preceding experiment. After the first treatment, excess solution was removed from the soil by suction. An additional 200 cc of the original solution was added and the treatment repeated. A third treatment was made in the same way. The data secured are presented in Table 4. In the second treatment, the calcium replaced was equal

TABLE 4.—*Net increases (M.E.) in calcium content of solutions containing sodium chloride and calcium chloride.*

Laboratory No.	Series 1				Series 2					Increase due to single treatment, %
	5 M.E. $CaCl_2$+ NaCl M.E.	Treatment No. 1	Treatment No. 2	Treatment No. 3	1.67 M.E. $CaCl_2$+ NaCl M.E.	Treatment No. 1	Treatment No. 2	Treatment No. 3	Total series 2	
12582, Ellis clay	2.5	0.53	0.02	0.00	0.83	0.23	0.11	−0.03	0.31	29
	5.0	0.95	0.24	0.11	1.67	0.41	0.19	0.05	0.65	46
	7.5	1.30	0.38	0.14	2.50	0.58	0.29	0.09	0.96	35
	10.0	1.52	0.46	0.20	3.33	0.76	0.36	0.08	1.20	27
7147, San Antonio silty clay loam	2.5	0.50	0.12	0.15	0.83	0.26	0.10	0.05	0.41	22
	5.0	0.93	0.29	0.21	1.67	0.46	0.17	0.12	0.75	24
	7.5	1.22	0.39	0.26	2.50	0.66	0.30	0.18	1.14	7
	10.0	1.40	0.71	0.22	3.33	0.90	0.40	0.21	1.51	23
21067, Trinity clay	2.5	0.56	0.23	0.08	0.83	0.23	0.10	0.06	0.39	43
	5.0	1.13	0.34	0.03	1.67	0.54	0.21	0.09	0.84	35
	7.5	1.56	0.59	0.15	2.50	0.76	0.32	0.17	1.25	25
	10.0	1.85	0.83	0.50	3.33	0.91	0.43	0.17	1.51	22
18542, Wilson clay	2.5	0.60	0.14	0.15	0.83	0.20	0.09	0.09	0.38	58
	5.0	1.12	0.25	0.16	1.67	0.40	0.29	0.15	0.84	33
	7.5	1.53	0.40	0.23	2.50	0.56	0.30	0.27	1.13	35
	10.0	1.91	0.65	0.34	3.33	0.75	0.38	0.31	1.44	33
Calcium replaced as percentage of sodium		19	6	3		26	12	6		31

to about one-third of that replaced by the first treatment, while in the third treatment, the replacement was less than one-fifth that of the first. These data indicate that the soil rapidly tends to reach a condition in which the further applications of a saline water has comparatively little additional effect.

Results of the preceding experiment brought up the question as to whether the effect of a given quantity of salt is the same when applied in one or in several treatments. Accordingly, a second series of solutions with one-third of the concentration of calcium chloride and sodium chloride used in the first series were made up. The quantity of calcium replaced in the single treatment with the more concentrated solution (series 1, treatment 1) was about one-fourth to one-third larger than when the same quantity of salts was applied in three treatments with a more dilute solution (series 2, total). However the relative replacement per unit of salt for a given treatment was higher with the more dilute solution (26%, 12%, and 6% compared with 19%, 6%, and 3%). The data show that less damage to a soil will result from a number of treatments with a dilute solution than from a single application of a more concentrated solution. They emphasize the importance of using irrigation water with a low concentration of salts.

In all of the preceding experiments, the quantity of calcium was kept constant while the quantity of sodium varied. One experiment was conducted in which the quantity of sodium was kept constant at 3.5 M.E., while the quantity of calcium was varied from 0 to 7.00 M.E. in the 200 cc of water. The net increases in calcium are given in Table 5. When the quantity of calcium chloride was increased from 0 to 7 M.E., the relative replacement of calcium by the sodium decreased from an average of 39% to 14%. These results agree with those reported in Table 2.

TABLE 5.—*Net increases (M. E.) in calcium content of solutions containing sodium chloride and varying quantities of calcium chloride.*

Laboratory No.	Sodium chloride, M. E.	3.50	3.50	3.50	3.50	3.50
	Calcium chloride, M.E.	0	1.75	3.50	5.25	7.00
12582	Ellis clay	1.32	1.10	0.90	0.79	0.75
7147	San Antonio silty clay loam	1.50	1.09	0.95	0.78	0.71
21067	Trinity clay	1.55	1.13	0.95	0.84	0.57
18542	Wilson clay	1.11	0.47	0.23	0.06	0.01
Net calcium as per cent of sodium		39	26	22	18	14

In the preceding work, the soil was brought into equilibrium with the solutions in static systems. In irrigation, the solution in contact with the soil may leach downward and be replaced by a new solution of the original concentration. In order to determine whether the conclusions reached from the work reported above were valid under such conditions, an experiment was set up in which 100 grams of soil in 1-inch glass tubes were leached with solutions containing 1.25 M.E. of calcium and 0 to 3.75 M.E. of sodium chloride. Successive 100-cc

portions of the solution coming through the soil were analyzed for calcium and the net change calculated. The results are given in Table 6. The average replacement of calcium, expressed with relation to the sodium in solution, was quite high (55%) in the first percolate, but the quantity in the succeeding percolates decreased rapidly to 31% in the second, 21% in the third, and 4% in the sixth. The results corroborate those secured in the earlier experiments tending to show that equilibrium is comparatively rapidly established, after which the further additions of the solution have little effect on the soil. The soils in this experiment were not allowed to come to dryness before the next addition of irrigation water was made. Had that been done, the results might have been different.

TABLE 6.—*Net increase (M. E.) in calcium content of successive lots of percolate caused by sodium chloride in the leaching solution.*

Laboratory No.	NaCl per 100 cc M. E.	Percolate No.					
		1	2	3	4	5	6
29427, Crockett clay loam	1.25	0.55	0.17	0.05	0.03	0.02	−0.03
	2.50	0.86	0.35	0.17	0.07	0.05	−0.02
	3.75	1.05	0.54	0.33	0.09	0.06	−0.01
12582, Ellis clay	1.25	1.09	0.38	0.23	0.12	0.05	0.04
	2.50	1.65	0.58	0.56	0.16	0.16	0.21
	3.75	2.49	0.94	0.77	0.23	0.15	0.06
7147, San Antonio silty clay loam	1.25	0.94	0.53	0.45	—	—	—
	2.50	1.54	1.19	0.62	—	—	—
	3.75	2.37	1.65	0.48	—	—	—
21067, Trinity clay	1.25	0.90	0.43	0.48	0.16	0.22	0.06
	2.50	1.86	0.99	0.99	0.69	0.60	0.25
	3.75	2.55	1.45	1.09	0.61	0.46	0.15
18542, Wilson clay	1.25	0.79	0.39	0.23	0.19	0.07	0.07
	2.50	1.23	0.77	0.56	0.38	0.21	0.16
	3.75	1.58	1.04	0.69	0.54	0.30	0.27
Calcium replaced as percentage of sodium		55	31	21	11	8	4

SUMMARY

Calcium chloride and sodium chloride, in equal equivalent concentration, and together equivalent to the exchangeable hydrogen in a hydrogen-saturated soil, replaced about 20% of the exchangeable hydrogen. Calcium absorbed represented about 75% of this quantity, leaving 25% for sodium. Calcium was thus three times as active as sodium in replacing hydrogen.

When 50 grams of soil were shaken with 200 cc of solutions containing 2.5, 5.0, 7.5, and 10.0 M.E. of sodium chloride, the average net increase in calcium content of the solutions was equivalent to 36, 32, 30, and 30%, respectively, of the sodium originally present. The addition of 5 M.E. of calcium chloride to the solutions caused a de-

crease in net calcium of about 50% of that found in the solutions containing sodium chloride alone. When sodium bicarbonate was used instead of sodium chloride, the net calcium was very small and decreased with an increase in bicarbonate concentration.

Replacement of calcium from soil receiving a second shaking with solutions containing sodium chloride and calcium chloride was equal to about one-third that in the first shaking, while that in the case of soil shaken three times was less than one-fifth of that in the first shaking. A single shaking with a concentrated solution replaced about one-third more calcium than was replaced by the same quantity of salt applied in three shakings.

Calcium replaced by solutions containing 3.5 M.E. of sodium chloride and 0, 1.75, 3.50, 5.25, and 7.00 M.E. of calcium chloride was equivalent to 39, 26, 22, 18, and 14%, respectively, of the sodium chloride present.

Calcium replaced by solutions containing 1.25 M.E. calcium chloride and varying quantities of sodium chloride per 100 cc in six successive percolates represented 55, 31, 21, 11, 8, and 4% of the sodium chloride originally present.

LITERATURE CITED

1. Kelley, W. P. The determination of the base-exchange capacity of soils and a brief discussion of the underlying principles. Jour. Amer. Soc. Agron., 21: 1021–1029. 1929.
2. ————. The agronomic significance of base exchange. Jour. Amer. Soc. Agron., 22:977–985. 1930.
3. Jenny, Hans. Studies on the mechanism of ionic exchange in colloidal aluminum silicates. Jour. Phys. Chem., 36:2217–58. 1932.

NEW SMUT AND RUST RESISTANT OATS FROM MARKTON CROSSES[1]

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VARIETIES of oats highly resistant to stem rust have long been known. The same is true with respect to smut. Satisfactory resistance to crown rust, on the other hand, is a comparatively recent discovery. However, there are as yet no varieties in commercial production in which high resistance to all three diseases are combined and, further, except for Rainbow, there is no oat variety widely grown commercially that has marked resistance to more than one major oat disease. The adaptation of Rainbow is comparatively limited.

In 1927, a definitely planned hybridization program was started by the authors to produce oat varieties for the north central states which would have resistance to more than one of these diseases. This program has now been conducted for 12 years and numerous selections having resistance to two or more diseases have resulted. The exceptional promise of many of these selections seemingly justifies bringing them to the attention of plant breeders and the presentation of data regarding them.

THE PARENT VARIETIES

The varieties used in these crosses were Markton (C.I. 2053)[3], Iogold (C.I. 2329), Richland (Iowa 105, C.I. 787), Edkin (C.I. 2330), Rainbow (C.I. 2345), and Iowa 444 (C.I. 2331). All have been so fully

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[3]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

described[4] and are so well known as to need only general descriptions here. They are classified morphologically as common yellow oats of *Avena sativa*, except Iowa 444, which is a common white oat, and all have the typical "sativa type" of floret separation and occasionally bear straight to twisted-geniculate awns, although Markton usually is awned and Rainbow usually is awnless.

Markton is a midseason oat; Rainbow and Iowa 444 are slightly earlier in maturity than are the typically midseason varieties such as Victory. Richland, Iogold, and Edkin are selections from Kherson, the well-known early oat of the Corn Belt.

Markton has so far proved highly resistant to the well-known races of both loose and covered smut (*Ustilago avenae* and *U. levis*) found in the United States. Richland is resistant to certain races of both the covered and loose oat smuts that attack Fulghum. Markton is extremely susceptible to all known races of both stem and crown rusts of oats (*Puccinia graminis avenae* and *P. coronata avenae*), whereas Richland, Iogold, and Rainbow are all resistant to the common physiologic races of stem rust (*P. graminis avenae*), Nos. 1, 2, 3, 5, and 7.[5] Although these varieties are susceptible to races 4, 6, 8, 9, and 10, the fact that races 2 and 5 probably constitute 98% of the stem rust that occurs in the United States has so far made their resistance highly effective as a protection against stem rust injury. Data from uniform rust nurseries[6] indicate that Edkin has considerable resistance to stem rust and possible resistance to some physiologic races of crown rust.

In addition to being resistant to stem rust Rainbow is resistant to certain physiologic races of crown rust (*Puccinia avenae coronata*) but completely susceptible to many other races of that disease. The writers have observed that Iowa 444 is heterozygous for resistance to certain races of both rusts.

Markton is well adapted to the western intermountain irrigated and dry-land areas. Rainbow is suited to the Red River Valley and elsewhere in North Dakota and the upper Mississippi Valley. Iowa 444 is productive in central and northern Iowa and has yielded comparatively well in northern Michigan. Richland (Iowa 105) and Iogold are grown extensively throughout the central and southern portions of the Corn Belt. Later maturing oats have proved better adapted farther north. Edkin, although approximating Iogold and Richland in yield in Iowa, is not superior to them and has never been distributed.

[4]STANTON, T. R., STEPHENS, D. E., and GAINES, E. F. Markton, an oat variety immune from covered smut. U. S. D. A. Circ. 324. 1924.

LEVINE, M. N., STAKMAN, E. C., and STANTON, T. R. Field studies on the rust resistance of oat varieties. U. S. D. A. Tech. Bul. 143. 1930.

STANTON, T. R., GAINES, E. F., and LOVE, H. H. Registration of varieties and strains of oats, IV. Jour. Amer. Soc. Agron., 21:1175–1180. 1929.

[5]LEVINE, M. N., and SMITH, D. C. Comparative reaction of oat varieties in the seedling and maturing stages to physiologic races of *Puccinia graminis avenae*, and the distribution of these races in the United States. Jour. Agr. Res., 55:713–729. 1937.

[6]See LEVINE, STAKMAN, and STANTON, footnote 4.

BREEDING METHODS

All crosses discussed in this paper were made in the greenhouse at the Arlington Experiment Farm, Arlington, Va. The following crosses were made in 1927: Richland (Iowa 105) × Markton (Cross No. X2712)[7], Markton × Iogold (No. X2737), and Edkin × Markton (No. X2738). In 1928, the crosses Iowa 444 × Markton (No. X2868) and Markton × Rainbow (No. X2871) were made. The heavy losses resulting from crown rust in 1927 prompted crossing Markton on varieties having resistance to this disease. In 1927–28, certain strains of Green Russian, such as Rainbow and Morota (C.I. 2344), and Iowa 444, offered the most promising source of resistance available, as such crown rust resistant varieties as Victoria and Bond were as yet unknown in the United States.

Although numerous exceptionally promising selections have resulted from the crosses of Markton with Rainbow and with Iogold, thus far no unusually worthy selections have evolved from the crosses with Richland or Edkin, and because of susceptibility to smut, all selections from the Iowa 444 cross were discarded by the end of 1934.

Some 5,000 selections have been made from progenies of the five crosses during the period from 1927 to 1937, and a few that have survived the pathological and the yield nursery tests have been advanced to replicated field plat experiments. Seedings were made on numerous experiment stations in 1936 and 1937.

Seedings have been made both in the greenhouse and in the field nursery. The objects of seeding in the greenhouse have been (a) to speed up the breeding program by growing an additional generation each year and (b) to determine with greater certainty the smut and rust reaction of the segregates so that the susceptible ones could be eliminated promptly. Moisture and temperature can be controlled somewhat in the greenhouse and control of these factors increases the chances of susceptible segregates becoming diseased.

Oats can be grown to perfection under irrigation at Aberdeen, Idaho. Under the late cool conditions there excellent crops of oats from May sowing have been obtained from seed grown in the greenhouse elsewhere and harvested in April. In consequence, alternate generations of many crosses have been grown in the greenhouse at Arlington, Va., and in the nursery at Aberdeen, Idaho.

In testing for smut susceptibility the seed of the selections has repeatedly been hulled and blackened with smut spores. This has served effectively in eliminating the highly susceptible selections in early generations and only resistant ones were retained. Early tests of the stem rust resistance were conducted in the greenhouse at Arlington but later tests have been made in the field at Ames, Iowa. In the greenhouse the adult plants were thoroughly wetted by a very fine spray of tap water and the rust spores, mixed with talc, were dusted over the plants. Some stem rust occurs naturally at Ames nearly every year and a few very effective natural epidemics have occurred. At all times the practice has been followed of eliminating stem rust susceptible strains whenever observed.

Crown-rust epidemics occurred naturally at Ames in 1935, 1936, and 1937 among selections from these crosses, but selections resistant to crown rust occurred only in the Markton × Rainbow cross. Data have been recorded on the reaction to crown rust of these selections in all three years and special attention

[7]All crosses discussed in this paper were made by F. A. Coffman, and the system used for numbering these crosses is as follows: e.g., X 2737 indicates a cross; the first two digits (27) indicates the year the cross was made; and the subsequent digits (37) the number of the cross of that particular year.

has been accorded selections that were homozygous for resistance. The type of resistance found in Rainbow and in the Markton × Rainbow crosses is not equal to that found in Victoria or Bond oats but has been sufficient for considerable protection against such crown rust as has occurred in recent years in the area to which these selections are likely to be adapted. Data also were obtained on the crown rust and stem rust resistance of many selections from an artificially inoculated nursery at Ames in 1935.

Promising selections from these crosses were obtained by both the pedigree and bulk nursery methods. Most of the selections from the Markton × Iogold and Richland × Markton crosses were secured from the pedigree cultures, but the bulk method was used exclusively in growing the early generations of the Markton × Rainbow and Edkin × Markton crosses. The bulk method may not be fully adequate in breeding for resistance to several diseases simultaneously.

HISTORY OF THE CROSSES

MARKTON × IOGOLD

The two seeds obtained of cross X2737, Markton × Iogold, were sown at Aberdeen, Idaho, in 1927. The seed produced on F_1 plants was divided, part being sent to the Brooklyn Botanic Garden, Brooklyn, N. Y., and part being planted in the greenhouse at Arlington Farm. From the lot planted at Arlington the F_2 generation was grown *en masse* in the greenhouse, the F_3 was grown at Aberdeen, Idaho, and the F_4 to F_{12} generations were grown at Ames, Iowa. Duplicate seedings of the F_9 generation were grown at Ames and at Aberdeen. Selections were made from F_4 and F_5 generation bulked material at Ames in 1930 and 1931. Re-selections were made at Aberdeen in 1934 and a few such re-selections were again re-selected at Ames in 1935. In 1937, 13 selections resulting as progenies of oat plants grown in the greenhouse at Arlington in 1927–28 remained.

Most of the promising selections from this cross have resulted from the F_2 seed sent to George M. Reed, Brooklyn, N. Y., in the winter of 1927–28. These selections were handled by the pedigree method and selections were made in F_2 and F_3 generations at Brooklyn[8], and in the F_4 generation at Lincoln, Nebr. In each of these three tests the seed was hulled and inoculated with smut before seeding.

Part of the F_5 lines were grown at Ames and part at Aberdeen in 1931, and all lines were grown at Ames for the first time in F_6 in 1932. Only six of these original lines were grown at Ames in 1937. Re-selections of this material were made at Ames, Arlington, or Aberdeen from 1932 to 1934, inclusive.

All of the more promising selections were derived as re-selections from the four lines Nos. 200, 307, 308, and 310. These re-selections were made at Aberdeen, Idaho, in F_8 in 1933. The latter three lines are progenies of the same F_2 plant and the last two of the same F_3 plant. Selections and re-selections numbering some 2,000 have been made from the Markton × Iogold cross. Probably not more than 20 of these selections will be grown in 1938.

[8]Stanton, T. R., Reed, George M., and Coffman, F. A. Inheritance of resistance to loose smut and covered smut in some oat hybrids. Jour. Agr. Res., 48:1073–1083. 1934.

RICHLAND × MARKTON

The F_1 generation of the Richland × Markton cross, X2712, consisting of four plants, was grown at Aberdeen, Idaho, in 1927. The seed produced by the F_1 plants was divided, part being sown at the Brooklyn Botanic Garden, Brooklyn, N. Y., in the winter of 1927–28 and part in the nursery at Ames, Iowa, in 1928. Selections from each of these two lots remained in the tests in 1937. Many of these selections are from the former group and their history is almost identical with that of the Markton × Iogold selections which were handled by the pedigree method at Brooklyn. Strains grown in 1937 at Ames resulted from two selections made in the F_4 generation at Aberdeen in 1930. Re-selections from these lines were made in the F_8 generation in 1933 at Aberdeen. Probably only two or three of these re-selections will be sown in 1938.

The lot of seed sent to Ames in 1928 was grown *en masse* for five generations. From it 100 selections were made in the F_4 in 1930 and 87 in F_5 in 1931. Several of these have considerable promise. A few re-selections of some strains were made in 1934 at Aberdeen, Idaho. More than 1,100 selections and re-selections have been made from this cross and probably not more than 12 will be grown in 1938.

EDKIN × MARKTON

The Edkin × Markton cross made in the greenhouse at Arlington Farm and planted at Aberdeen, Idaho, in 1927 produced one F_1 plant. This cross was grown in bulk in the next four generations at Ames from 1928 to 1931. One hundred selections were made in the F_4 generation in 1930 and 82 in the F_5 generation in 1931. Only three of the selections made in 1931 remained in 1937 and of these two were then in the F_{11} generation and one in the F_{10}.

MARKTON × RAINBOW

The three seeds obtained from this cross were planted at Aberdeen, Idaho, in 1928. The F_2 generation was grown in the greenhouse at Arlington Farm in the winter of 1928–29, and the F_3 to F_5 generations were grown in bulk at Ames, Iowa, from 1929 to 1931. A total of 75 selections was made from the F_4 rows in 1930 and 139 from the F_5 rows in 1931. Numerous re-selections were made at Aberdeen and Arlington from 1932 to 1935 from the original selections made at Ames in 1930. A total of 179 such re-selections made at Aberdeen in 1934 was grown in the pathologic nursery at Ames in 1935, where artificially produced stem and crown rust epidemics proved many to be heterozygous for resistance. Re-selections were again made from such rows. Of the 179 re-selections 74 were grown in the F_{13} generation in 1937. Many of these selections, especially from line 708, are resistant to smut, stem rust, and certain races of crown rust, and produce excellent yields of grain of good quality. In addition, some of them have unusually stiff straw and have given strong indications of being resistant to heat and drought.

The group of 139 selections, made from the original bulked rod-row material in the F_5 generation in 1931, has not been re-selected extensively. These selections were grown in the F_6 to F_{11} generations at Ames, Iowa. Only eight were grown in 1937. Some of them are disease resistant and excellent in yield. A total of some 1,100 selections of this cross have been grown and in some cases re-selections have been made as many as five times between F_7 and F_{13} generations.

SMUT RESISTANCE OF SELECTIONS

Losses from the oat smuts (*Ustilago avenae* and *U. levis*) exceed those from any other disease of oats in the United States.[9] As a consequence, breeding for resistance to smut was first given attention in the present oat breeding program of this Division. Most segregates from which the present selections of the Richland × Markton and Markton × Iogold crosses have resulted were handled by the pedigree method in the F_2 and F_3 generations at Brooklyn Botanic Garden in 1928 and 1929. The F_4 generation of the former cross was grown in pedigree rows at Aberdeen, Idaho, and of the latter at Lincoln, Nebr., in 1930. In all three generations the kernels were hulled and then blackened with spores prior to seeding. Although these selections were free from smut in all three years, they were later found to be heterozygous for resistance in additional tests. Complete elimination of susceptible segregates in these lines had not been accomplished in the F_{13} generation. This may be due to (1) heterozygosity in strains selected, (2) the introduction of new smut races into the cultures, and (3) hybridity or impurity of the smut races used as inoculum. In the tests conducted at Ames, the smut spores employed were from collections made in Iowa, usually at Ames.

Selections from these same crosses made from plants grown *en masse* until the F_5 generation have, on testing, often proved only slightly less resistant than those handled by the pedigree method.

No selections were made from the Markton × Rainbow and Edkin × Markton crosses until the F_4 and F_5 generations. Since that time these strains have been tested repeatedly for smut resistance. The results obtained indicate that, on the average, these selections are only slightly less resistant than those of the Iogold and Richland crosses, which were handled by the pedigree method for the three successive early generations. There is no doubt, however, that more of the strains resulting from repeated re-selection are entirely free from smut than is the case among those selected only once or twice. Although immunity for smut resistance has rarely been obtained even by repeated selection, there seems ample reason for the belief that a practical degree of resistance to smut can be obtained with comparative ease. Data on the smut resistance of the oat selections from all crosses are presented in Table 1. This table does not include data in the F_2 to F_4 generations of strains grown by the pedigree method in which seed of all selections was smutted prior to seeding. Although a few smutted panicles have been observed in some tests, the data presented indicate that these selections, as compared with Iogold, are highly resistant to smut and there is little doubt but that all of these selections are extremely resistant to those smut races ordinarily found in the Corn Belt.

RUST RESISTANCE OF SELECTIONS

A study of the reaction of the selections from the several crosses to physiologic races 2 and 5 of stem rust of oats (*Puccinia graminis*

[9]Based on figures published in supplements of the Plant Disease Reporter, Bureau of Plant Industry, U. S. Dept. of Agriculture.

avenae) was initiated in 1930. The F_4 generation of the cross Markton × Iogold was grown in 1930 at Lincoln, Nebr., where a natural epidemic of stem rust occurred and selections of plants resistant to rust and smut were made by the senior writer. Among a large number of rust-resistant selections that year were the four plants from which the strains, 200, 307, 308, and 310, were derived. Table 2 presents data recorded on rust resistance of leading re-selections from these strains in tests conducted during the period 1931 to 1937, inclusive.

At Ames, during the period from 1931 to 1935, the practice of discarding all susceptible selections from these Markton crosses was followed. Some of the exceptional lines that were heterozygous for resistance were re-selected. Consequently, any selections from any of these crosses grown in the tests in 1937 had proved resistant to stem rust in numerous tests and resistant selections only are included in Table 2. In 1932–33 numerous selections were grown in the greenhouse at Arlington Farm under test of an artificially created epidemic of stem rust. Only rust-resistant selections were retained.

In 1933, many selections were grown in a breeding garden at Ames, again under test of an artificially induced rust epidemic, and, again, only resistant selections were retained. In the winter of 1933–34 a number of re-selections were grown in the greenhouse at Arlington. These were subjected to an artificial epidemic of stem rust, physiologic race 2. In 1934, the progeny of these plants were planted at Ames, but, because of extreme drought, the seed was lost. In 1935, 1936, and 1937 these selections were grown at Ames and elsewhere, and data obtained on their rust resistance are presented in Table 2. Prior to 1935 no data were recorded at Ames on the resistance to crown rust in any of these selections. In 1935 a serious naturally induced epidemic of crown rust occurred in Iowa, where, according to estimates, it caused a 20% reduction in yield. Many selections from the cross Markton × Rainbow proved highly resistant to crown rust at Ames that year, and the data obtained on the behavior of these selections are presented in Table 2. Further observations were made in 1936 and 1937. Fig. 1 shows the effect of both crown and stem rust on parental lines and certain selections from the Markton × Rainbow cross in Iowa in 1935. There seems little doubt that certain of these selections are as highly resistant to both stem and crown rust as is Rainbow and are likewise resistant to smut.

YIELD OF SELECTIONS

Disregarding their disease resistance, yield alone would make many of these selections of exceptional interest. Yield data obtained from tests in the Corn Belt are presented in Table 3 and those from other sections in Table 4.

The yielding ability of these selections as compared with the present standard oat varieties grown on the different stations in the Corn Belt is highly encouraging. Selections from the crosses Markton × Rainbow and Markton × Iogold have been especially high yielding in numerous tests. The high-yielding selections from the latter cross all trace back to four F_4 selections, Nos. 200, 307, 308, and 310, made at Lincoln in 1930. As a result of this close relationship these

TABLE 1.—*Reaction to smut of leading selections from four Markton oat crosses.*

Selection or variety	C. I. No.	Number of smutted plants in greenhouse tests at Arlington, Va.*		Number of smutted panicles per row										
				Aberdeen, Idaho†		Iowa**								
						Ames						Kanawha		
		1932–33‡	1933–34	1933‡	1934	1932‡	1933‡	1934§	1935	1936	1937*	1935	1936	1937*
						Richland×Markton (×2712)								
524–5	——	0	0	0	0	0	0	0	0	0	0	—	0	0
–13	——	—	0	—	0	—	—	0	||	9	7	0	10	—
588–6	——	0	0	0	0	0	0	0	0	0	0	0	0	0
2411	3363	—	—	—	0	0	0	0	0	0	0	0	1	0
2444	3364	—	—	—	0	0	0	0	0	2	2	0	0	9
						Markton×Iogold (×2737)								
200–4	——	0	0	0	0	0	0	0	0	1	0	0	0	0
–41481	——	—	—	—	—	—	—	0	0	0	3	—	0	0
–41486	3509	—	—	—	—	—	—	0	0	0	0	—	0	0
–41493	3510	—	—	—	—	—	—	0	0	1	0	—	0	0
–41499	3352	—	—	—	—	—	—	0	0	0	6	—	0	4
–41509	3353	—	—	—	—	—	—	0	0	1	3	—	0	1
307–41530	3512	0	—	0	—	0	0	0	0	0	0	—	0	0
–41534	——	—	—	—	—	—	—	—	0	0	0	—	0	0
–41541	3513	—	—	—	—	—	—	0	0	0	0	—	0	0
–41561	——	—	—	—	—	—	—	0	0	0	0	—	0	0
308–3	3237	0	0	0	0	0	0	0	0	0	0	0	0	0
–5	3239	—	0	—	0	—	—	0	0	0	—	0	0	—
–41568	3356	—	—	—	—	—	—	0	0	0	0	—	0	0
–41576	3357	—	—	—	—	—	—	0	0	0	0	—	0	0
–41580	3358	—	—	—	—	—	—	0	0	0	0	—	0	0
310–41626	——	0	—	0	—	0	0	0	0	0	0	—	0	—

Edkin×Markton (×2738)														
2586	—	–	–	–	0	0	0	0	0	1	3	0	3	1
2588	3365	–	–	–	0	0	0	0	0	1	0	0	1	0
Markton×Rainbow (×2871)														
668	3241	–	–	–	0	0	0	0	0	0	0	0	0	0
684–3	3341	0	0	0	0	0	0	0	0	0	0	0	0	0
–5	3342	–	0	–	0	–	–	0	0	1	0	0	0	0
–6	3244	–	0	–	0	–	–	0	0	0	0	0	0	0
–9	3343	–	0	–	0	–	–	0	0	0	2	0	0	0
–41913	—	–	–	–	–	–	–	0	0	0	0	–	0	5
–41944	3505	–	–	–	–	–	–	0	0	0	0	–	0	0
708–2	3346	0	0	0	0	0	0	0	0	1	5	0	0	0
–3	3247	–	0	–	0	–	–	0	0	0	4	0	0	7
–41974	—	–	–	–	–	–	–	0	0	0	8	–	0	1
–41978	3506	–	–	–	–	–	–	0	0	0	2	–	0	0
–41980	3507	–	–	–	–	–	–	0	0	0	2	–	0	0
–41983	3508	–	–	–	–	–	–	0	0	1	1	–	0	0
709	3348	–	–	–	0	0	0	0	0	0	3	0	0	0
1907	—	–	–	–	–	0	0	2	0	0	0	0	0	0
1943	3350	–	–	–	1	0	0	0	0	0	2	0	0	0
1965	3351	–	–	–	0	0	0	0	0	1	1	‖	0	0
1988	—	–	–	–	0	0	0	0	0	0	0	0	0	0
Markton	2053	–	0	0	2	–	0	0	0	0	0	–	–	0
Iogold	2329	7¶	5¶	2	49	‖	‖	20	‖	32	78	‖	17	61

*Tests made with hulled and inoculated seed.
**Except where noted, data from rod rows normally containing 400 to 500 panicles. Seed not inoculated with smut.
†Tests made with unhulled and inoculated seed sown in 5- to 8-foot rows.
‡Data from parent selections.
§Data from parent selections grown in 5-foot rows.
‖Smut present but no counts made.
¶Richland substituted for Iogold. Seven of 15 panicles smutted in 1933 and 5 of 15 in 1934.

TABLE 2.—*Reaction to rust of leading selections from four Markton oat crosses.*

Selection or variety	C. I. No.	Severity of infection						
		Stem rust				Crown rust		
		Type		Coefficient		Coefficient		
		Arlington, Va.		Ames, Iowa		Ames, Iowa		Kanawha, Iowa
		1932–33	1933–34	1936	1937	1935	1937	1935
Richland×Markton (×2712)								
524-5	—	1	2	S*	—	—	+†	—
-13	—	—	2	S	—	—	+	—
588-6	—	1	3	0	1	—	50	—
2411	3363	—	—	0	1	—	45	—
2419	—	—	—	0	1	—	+	—
2444	3364	—	—	0	1	—	36	—
Markton×Iogold (×2737)								
200-4	—	1	2	0	1	—	36	—
-9	—	—	2	0	1	—	36	—
-41481	—	—	—	0	1	—	36	—
-41486	3509	—	—	0	1	—	36	—
-41493	3510	—	—	0	1	—	40	—
-41499	3352	—	—	0	1	—	50	—
-41509	3353	—	—	0	1	—	60	—
307-41530	3512	1	—	0	1	—	45	—
-41534	—	—	—	0	1	—	36	—
-41541	3513	—	—	0	1	—	36	—
-41561	—	—	—	0	1	—	45	—
308-2	—	1	3	0	—	—	36	—
-3	3237	—	2	0	1	—	36	—
-5	3239	—	2	0	—	—	+	—
-41568	3356	—	—	0	1	—	36	—
-41578	3357	—	—	0	1	—	36	—
-41580	3358	—	—	0	1	—	36	—
-41585	—	—	—	0	—	—	+	—
310-41626	—	1	—	0	—	—	+	—
Edkin×Markton (×2738)								
2586	—	—	—	0	2	—	50	—
2588	—	—	—	0	1	—	50	—
Markton×Rainbow (×2871)								
668	3241	—	—	0	1	12	16	6
684-3	3341	1	3	0	1	12	16	6
-5	3342	—	2	0	1	12	16	6
-6	3244	—	2	0	1	12	16	8
-9	3343	—	2	0	1	S	24	10
-41913	—	—	—	0	1	3	40	—
-41925	—	—	—	0	1	2	40	—
-41944	3505	—	—	0	1	3	16	—
708-2	3346	2	2	0	1	S	S	+
-3	3247	—	2	0	1	4	9	4
-41974	—	—	—	0	1	1	4	—
-41975	—	—	—	0	1	1	4	—
-41978	3506	—	—	0	1	3	6	—
-41980	3507	—	—	0	1	2	6	—

TABLE 2.—*Concluded.*

Selection or variety	C. I. No.	Severity of infection						
		Stem rust				Crown rust		
		Type		Coefficient		Coefficient		
		Arlington, Va.		Ames, Iowa		Ames, Iowa		Kanawha, Iowa
		1932–33	1933–34	1936	1937	1935	1937	1935
Markton×Rainbow (×2871)								
708–41981	—	—	—	0	1	1	6	—
–41983	3508	—	—	0	1	1	6	—
709	3348	—	—	0	1	+	32	+
1907	—	—	—	0	1	S	8	—
1943	3350	—	—	0	1	6	6	6
1965	3351	—	—	S	1	S	S	S
1976	—	—	—	0	1	S	6	—
1988	—	—	—	0	1	S	6	S
2016	3248	—	—	0	1	80	S	—
Markton	2053	—	—	10	40	90	80	70
Iogold	2329	—	2	0	1	80	50	40

*S = Segregating for resistance. Method of computing coefficient values is that used by Levine, Stakman, and Stanton (footnote 4, p. 798).
†+ = Susceptible.

lines appear to be similar in yield although certain selections from the lines 200 and 308 may be slightly superior.

The Richard × Markton and Edkin × Markton crosses produced few exceptional selections. Selections Nos. 524–5 and 2444 are the best from the former cross. Selection 524–5 resulted from the pedigree method, whereas selection No. 2444 was produced by the bulk method of breeding.

Only the bulk method of breeding was followed with cross Edkin × Markton. Possibly the best yielding selection resulting from that cross is No. 2588, although selection No. 2586 appears only slightly less productive.

Selections from the Markton × Rainbow cross have been far superior in yield to those from any of the other crosses and they also are highly resistant to disease. Yield data obtained in the Corn Belt (Table 3) indicate that many of these selections are much superior in yield as well as in disease resistance to standard varieties. Most of the highest yielding selections from this cross trace back to the two lines, Nos. 684 and 708, which were selected in the F_4 generation from a bulk population of the cross growing at Ames, Iowa. The re-selections from these lines on which data are presented were made at Aberdeen, Idaho, in 1933. The strains grown in 10 or more tests which seem most promising include Nos. 668, 684–3, 684–5, 684–41944, 708–3, 709, and 1965. Selection No. 708–3 (C.I. 3247) has been exceptionally outstanding for yield in Iowa. It has averaged 93.5 bushels per acre for a 3-year period at Kanawha and 75.9 bushels at Ames.

TABLE 3.—*Yield in bushels per acre of leading selections from four Markton oat crosses grown at stations in the Corn Belt compared with standard varieties.*

Selection or variety	C. I. No.	Ames, Iowa L. C. Burnett H. C. Murphy							Kanawha, Iowa L. C. Burnett H. C. Murphy				Emmetsburg, Iowa L. C. Burnett	Lincoln, Nebraska T. A. Kiesselbach				Urbana, Illinois George H. Dungan			La Fayette, Indiana G. H. Cutler	Columbus, Ohio J. B. Park	Station years grown	Av. yield	Dev. from comp. av. of check varieties
		1932	1933	1934	1935	1936*	1937	Av.	1935	1936*	1937	Av.	1935	1935	1936	1937	Av.	1936	1937	Av.	1937	1937			
											Richland×Markton (×2712)														
524-5	—	69.2†	39.0†	16.0†	37.0	67.0	88.4	64.1	—	97.0	—	97.0	—	—	—	—	—	—	—	—	—	—	4	72.4	+ 8.4
-13	—	—	—	—	40.5	74.2	86.2	67.0	50.5	74.0	—	62.3	40.5	—	—	—	—	—	—	—	70.9	—	7	62.4	− 1.2
588-6	—	74.6†	39.0†	20.5†	29.0	69.0	68.8	55.6	59.3	55.0	64.7	59.7	43.5	—	—	—	—	—	—	—	—	—	7	55.6	− 5.7
2411	3363	—	72.0	22.5	37.5	73.4	68.6	54.8	62.7	65.0	81.0	69.6	47.0	59.2	17.8	27.9	35.0	—	53.4	53.4	74.1	—	14	54.4	+ 1.1
2444	3364	—	72.0	16.5	44.3	76.8	80.4	58.0	63.8	62.7	87.0	71.2	49.0	50.4	21.7	34.7‡	35.6	—	57.3	57.3	76.0	—	14	56.6	+ 3.3
											Markton×Iogold (×2737)														
200-4	—	78.8†	65.0†	9.0†	56.5	71.4	98.4	75.4	75.5	70.7	88.0	78.1	48.0	—	—	—	—	42.2	—	42.2	70.5	—	9	69.0	+ 6.9
-41481	—	—	—	—	60.0	71.4	91.4	74.3	—	69.3	86.7	78.0	—	—	—	—	—	—	—	—	—	—	5	75.8	+ 9.4
-41486	3509	—	—	—	68.0	73.0	95.8	78.9	—	72.3	88.0	80.2	—	—	—	—	—	—	—	—	—	—	5	79.4	+13.0
-41493	3510	—	—	—	67.0	72.6	94.8	78.1	—	67.3	89.0	78.2	—	—	—	—	—	—	—	—	—	—	5	78.1	+11.7
-41499	3352	—	—	—	53.0	72.0	95.0	73.3	—	73.0	84.7	78.9	—	—	—	31.9	31.9	—	52.0	52.0	—	37.3	8	62.4	+ 4.0
-41509	3353	—	—	—	64.0	70.8	97.6	77.5	—	79.3	101.3	90.3	—	—	—	33.2	33.2	—	56.7	56.7	—	38.7	8	67.7	+ 9.3
307-41530	3512	73.2†	70.0†	13.0†	69.0	64.6	102.6	78.7	—	80.7	92.0	86.4	—	—	—	—	—	—	—	—	—	—	5	81.8	+15.4
-41534	—	—	—	—	62.0	61.8	94.6	72.8	—	76.7	88.3	82.5	—	—	—	—	—	—	—	—	—	—	5	76.7	+10.3
-41541	3513	—	—	—	61.0	63.8	97.0	73.9	—	85.3	92.7	89.0	—	—	—	—	—	—	—	—	—	—	5	80.0	+13.6
-41561	—	—	—	—	52.0	80.0	90.6	74.2	—	73.0	81.7	77.4	—	—	—	—	—	—	—	—	—	—	5	75.5	+ 9.1
308-3	3237	75.4†	71.0†	11.0†	71.0	69.2	98.2	79.5	69.8	71.0	83.0	74.6	51.0	—	—	39.3	39.3	40.6	52.2	46.4	81.6	40.0	12	63.9	+ 6.0
-5	3239	—	—	—	54.8	66.8	—	60.8	72.8	73.3	—	73.1	—	—	—	34.7	34.7	44.6	57.0	50.8	94.2	45.9	9	60.5	+ 4.4
-41568	3356	—	—	—	65.0	64.2	97.0	75.4	—	83.0	88.0	85.5	—	—	—	38.7	38.7	—	53.4	53.4	—	42.1	8	66.4	+ 8.0
-41576	3357	—	—	—	60.0	66.0	100.8	75.6	—	85.0	89.0	87.0	—	—	—	40.1	40.1	—	56.0	56.0	—	38.3	8	66.9	+ 8.5
-41580	3358	—	—	—	53.0	68.6	95.4	72.3	—	73.3	89.3	81.3	—	—	—	39.4	39.4	—	58.6	58.6	—	41.7	8	64.9	+ 6.5
310-41626	—	70.8†	60.0†	11.5†	52.0	73.0	100.8	75.3	—	70.0	—	70.0	—	—	—	—	—	—	—	—	—	—	4	74.0	+10.0
											Edkin×Markton (×2738)														
2586	—	—	95.0	18.0	46.8	69.0	86.4	63.0	66.0	64.3	77.0	69.1	39.5	—	—	—	—	—	—	—	86.3	—	10	64.8	+ 6.4
2588	3365	—	95.0	14.5	50.3	69.8	88.2	63.6	67.3	90.7	78.0	78.7	42.0	—	—	—	—	—	—	—	82.7	—	10	67.9	+ 9.5

Markton ×Rainbow (×2871)

668	3241	69.0	79.0	19.5	59.0	76.6	101.0	67.4	83.6	81.0	99.7	88.1	58.0	—	—	—	—	44.6	56.0	50.3	—	34.0	13	66.2	+13.8
684–3	3341	66.4†	93.0†	16.5†	59.0	76.6	89.8	75.1	85.0	73.7	94.7	84.5	60.5	—	—	—	—	54.1	66.3	60.2	—	39.8	10	70.0	+13.3
–5	3342	—	—	—	56.0	76.0	85.0	72.3	94.0	76.7	91.7	87.5	60.5	—	—	35.2	35.2	52.9	61.6	57.3	—	34.9	11	65.9	+11.2
–6	3244	—	—	—	54.0	78.0	94.6	75.5	69.9	90.0	93.0	84.3	—	—	—	—	—	—	60.6	60.6	—	35.8	8	72.0	+10.5
–9	3343	—	—	—	60.0	75.2	85.0	73.4	80.8	75.3	101.3	85.8	58.5	—	—	—	—	53.8	64.4	59.1	—	—	9	72.7	+15.1
–41913	—	—	—	—	47.0	71.0	81.2	66.4	—	85.0	101.3	93.2	—	—	—	—	—	—	—	—	—	—	5	77.1	+10.7
–41944	3505	—	—	—	42.0	81.0	95.0	72.7	—	81.0	92.7	86.9	—	—	—	—	—	—	—	—	—	—	5	78.3	+11.9
708–2	3346	79.4†	67.0†	14.5†	53.5	66.0	93.8	71.1	62.5	79.3	79.3	73.7	39.0	—	—	36.2	36.2	40.8	46.7	43.8	—	36.2	11	57.6	+ 2.9
–3	3247	—	—	—	49.5	76.6	101.6	75.9	90.4	92.7	97.3	93.5	—	—	—	35.5	35.5	48.6	63.0	55.8	—	46.5	10	70.2	+13.7
–41974	—	—	—	—	41.0	90.0	99.2	76.7	—	75.0	88.0	81.5	—	—	—	—	—	—	—	—	—	—	5	78.6	+12.2
–41978	3506	—	—	—	34.0	84.0	105.0	74.3	—	69.0	97.7	83.4	—	—	—	—	—	—	—	—	—	—	5	77.9	+11.5
–41980	3507	—	—	—	46.0	83.0	110.4	79.8	—	71.0	93.7	82.4	—	—	—	—	—	—	—	—	—	—	5	80.8	+14.4
–41983	3508	—	—	—	58.0	69.6	95.6	74.4	—	76.3	88.3	82.3	—	—	—	37.2	37.2	—	49.7	49.7	—	39.7	8	64.3	+ 5.9
709	3348	78.4	77.0	17.5	54.5	71.2	93.6	65.4	58.3	82.7	90.3	77.1	45.0	—	—	—	—	46.4	45.5	46.0	—	—	12	63.4	+10.7
1907	—	—	—	17.5	54.0	72.0	85.2	57.2	96.0	63.0	—	79.5	55.0	47.0	22.2	37.4	35.5	—	—	—	—	—	10	54.9	+ 7.0
1943	3350	—	89.0	19.0	57.0	76.0	93.6	66.9	81.5	66.7	96.3	81.5	73.0	30.4	22.2	37.5	30.0	45.8	55.0	50.4	—	40.0	15	58.9	+ 9.5
1965	3351	—	69.0	18.0	72.0	74.2	89.4	64.5	81.8	76.0	90.0	82.6	63.0	—	—	—	—	49.5	59.7	54.6	—	43.5	12	65.5	+13.1
1988	—	—	71.0	16.5	56.3	67.0	88.4	59.8	81.8	68.0	—	74.9	43.0	36.8	21.1	30.9	29.6	—	—	—	—	—	11	52.8	+ 4.9
Markton	2053	—	88.0	21.5	28.9	—	—	46.1	40.3	—	—	40.3	31.0	—	—	31.3	31.3	—	—	—	—	—	6	40.2	— 0.1
Iogold§	2329	52.5	47.8	14.5	46.9	70.3	76.6	51.4	59.9	62.1	76.2	66.1	37.1	46.4	29.6	36.3	37.4	41.9	—	41.9	—	—	14	49.9	+ 0.4
Rainbow	2345	—	44.8§	15.2§	56.3	68.7	—	46.3	73.5	—	—	73.5	57.5	—	21.4	29.1	25.3	46.9	—	46.9	—	—	9	45.9	+ 3.7
Yield of check variety‖	—	52.5	47.8	14.5	46.9	70.3	76.6	51.4	59.9	62.1	76.2	66.1	37.1	46.4	29.6	35.5	37.2	37.8	51.2	44.5	92.2	48.6	17	52.1	
Average all selections exclusive of checks		73.7	79.9	18.0	53.8	72.5	92.6	—	74.0	75.6	89.3	—	50.9	44.8	21.0	35.6	—	47.0	56.3	—	79.5	39.7	—	—	—

*Yields from most selections are weighted average yields from more than one test.
†Yield of parent selection from which re-selection was made. Data shown were omitted from all summary columns in table.
‡Average of several rows.
§Average usually of many rows. Consequently often not entirely comparable.
‖The check variety at Ames, Kanawha, and Emmetsburg, Iowa, and Lincoln, Nebr., was Iogold; at Urbana, Ill., Sixty-Day; at LaFayette, Ind., Gopher; and at Columbus, Ohio, Franklin. Yields of checks are not always entirely comparable, being averages of all checks in the test.

TABLE 4.—*Yield in bushels per acre of leading selections from four Markton oat crosses grown on stations in northern and western United States compared with standard varieties.**

Selection or variety	C. I. No.	Fargo, North Dakota Glenn S. Smith				Langdon, North Dakota Glenn S. Smith				Madison, Wisconsin H. L. Shands			East Lansing, Mich. J. W. Thayer, Jr.	Chatham, Michigan B. R. Churcchill	Ithaca, New York H. H. Love	Corvallis, Oregon D. D. Hill	Pendleton, Oregon J. F. Martin	Station years grown	Av. yield	Dev. from comp. av. of check varieties
		1935	1936	1937	Av.	1935	1936	1937	Av.	1936	1937	Av.	1937	1937	1937	1937	1937			
Richland × Markton (× 2712)																				
2411	3363	—	—	—	—	—	—	—	—	—	61.7	61.7	—	—	—	—	—	1	61.7	+7.9
2444	3364	—	—	—	—	—	—	—	—	—	51.9	51.9	—	29.4	—	—	—	2	40.7	−1.0
Markton × Iogold (× 2737)																				
200–4	—	—	—	—	—	—	—	—	—	28.9	—	28.9	—	—	—	—	—	1	28.9	−5.1
–41509	3353	—	—	—	—	—	—	—	—	—	51.6	51.6	69.9	—	—	—	—	2	60.8	+5.8
308–3	3237	—	—	—	—	—	—	—	—	35.3	56.2	45.8	—	—	—	57.6	48.4	4	49.4	−6.9
–5	3239	—	—	—	—	—	—	—	—	31.0	55.9	43.5	—	26.4	—	61.6	47.6	5	44.5	−6.4
–41568	3356	—	—	—	—	—	—	—	—	—	50.1	50.1	—	—	—	65.6	52.4	3	56.0	−7.7
–41576	3357	—	—	—	—	—	—	—	—	—	47.2	47.2	—	—	—	57.0	46.2	3	50.1	−13.6
–41580	3358	—	—	—	—	—	—	—	—	—	54.8	54.8	—	—	—	57.0	52.6	3	54.8	− 8.9
Edkin × Markton (× 2738)																				
2588	3365	—	—	—	—	—	—	—	—	—	62.7	62.7	56.8	18.7	—	—	52.8	4	47.8	− 4.6
Markton × Rainbow (× 2871)																				
668	3241	—	—	54.6	54.6	—	—	85.6	85.6	28.4	62.2	45.3	—	16.9	19.2	—	61.2	7	46.9	+ 2.5
684–3	3341	—	—	44.4	44.4	—	—	54.0	54.0	34.7	53.7	44.2	—	15.7	19.0	—	62.0	7	40.5	− 3.9
–5	3342	—	—	42.0	42.0	—	—	56.8	56.8	32.7	51.0	41.9	—	24.3	21.8	—	64.8	7	41.9	− 2.5
–6	3244	—	—	50.4	50.4	—	—	48.0	48.0	—	55.6	55.6	—	16.9	—	—	48.0	5	43.8	− 7.4
–9	3343	—	—	48.0	48.0	—	—	44.8	44.8	35.4	60.4	47.9	—	22.7	21.1	—	53.8	7	40.9	− 3.5
708–2	3346	—	—	32.8	32.8	—	—	20.8	20.8	34.5	47.5	41.0	51.6	22.3	34.5	—	56.2	8	37.5	− 8.4
–3	3247	—	—	51.6	51.6	—	—	46.0	46.0	33.9	49.6	41.8	63.4	34.7	40.4	—	67.8	8	48.4	+ 2.5
–41983	—	—	—	45.2	45.2	—	—	33.2	33.2	—	52.8	52.8	54.7	27.8	37.2	—	70.2	7	45.9	− 1.7
709	3348	—	—	57.6	57.6	—	—	—	—	34.9	49.1	42.0	60.7	32.4	32.9	—	56.6	7	46.3	+ 3.7
1907	—	—	15.7	43.2	29.5	—	15.5	74.8	45.2	—	—	—	—	—	—	—	—	4	37.3	+ 3.7
1943	3350	61.4	20.5	33.6	38.5	47.2	24.5	66.0	45.9	31.9	60.1	46.0	65.0	27.8	—	61.8	35.2	12	44.6	− 1.1
1965	3351	51.4	18.8	36.0	35.4	54.4	27.2	66.0	49.2	36.6	63.6	50.1	40.0	15.6	16.9	60.0	30.2	13	39.7	− 4.1
1988	—	50.2	19.5	57.0	42.2	40.4	19.6	60.0	40.0	—	—	—	—	—	—	—	—	6	41.1	+ 1.6
Markton	2053	—	—	—	—	—	—	—	—	—	—	—	—	—	—	73.0	70.0	2	71.5	+ 2.8
Iogold	2329	—	—	—	—	—	—	—	—	28.4	56.7	42.6	—	—	—	—	—	2	42.6	− 1.3
Rainbow	2345	54.5	15.1	30.4	33.3	48.1	19.0	68.8	45.3	31.0	—	31.0	—	—	—	60.6	69.8	9	44.1	− 1.3
Yield of check variety†		54.5	15.5	33.8	34.6	48.1	16.4	68.8	44.4	34.0	53.8	43.9	56.2	29.5	21.0	67.4	70.0	13	43.8	—
Average all selections exclusive of checks		54.3	18.6	45.9	—	47.3	21.7	54.7	—	33.2	54.9	—	57.8	23.7	27.0	60.1	53.3			

*Some of the selections were grown at Dickinson, N. Dak., from 1934 to 1937 inclusive. Only a few selections were grown in 1934 and 1935 and practically complete failures occurred in 1936 and 1937 due to drought and grasshoppers; consequently, no data from Dickinson are included.

†The check variety at Fargo and Langdon, N. Dak., was Rainbow; at Madison, Wis., State Pride; at East Lansing, Mich., Wolverine; at Chatham, Mich., Iowa 444; at Ithaca, N. Y., Cornellian; at Corvallis, Oreg., Victory; and at Pendleton, Oreg., Markton. Yields of checks are not always entirely comparable, being averages of all checks in the test.

These selections have been tested on stations outside the Corn Belt in fewer years. The data thus are less conclusive. Several selections yielding well in the Corn Belt have also been superior elsewhere. Selections from only the Markton × Rainbow cross have yielded well in sections where midseason oats are better adapted than are early oats. In tests conducted on stations to the north of the Corn Belt, selections from the Markton × Rainbow cross which seem superior are Nos. 668, 708–3, 709, 1907, and 1988. Several of these proved to be exceptional producers in tests in the Corn Belt also.

Markton, produced on the dry lands of eastern Oregon, has given ample proof of its drought and heat resistance in experiments in that area. Data obtained at Ames, Iowa, in 1934, the year of the great drought, indicate that at least a high degree of this ability probably was inherited by some of the selections, especially those from the Markton × Rainbow cross.

QUALITY OF SELECTIONS

Quality in oats has not been studied extensively in these tests, but its importance as indicated by test weight was recognized. Data recorded in 1935, 1936, and 1937 on weight per bushel of leading selec-

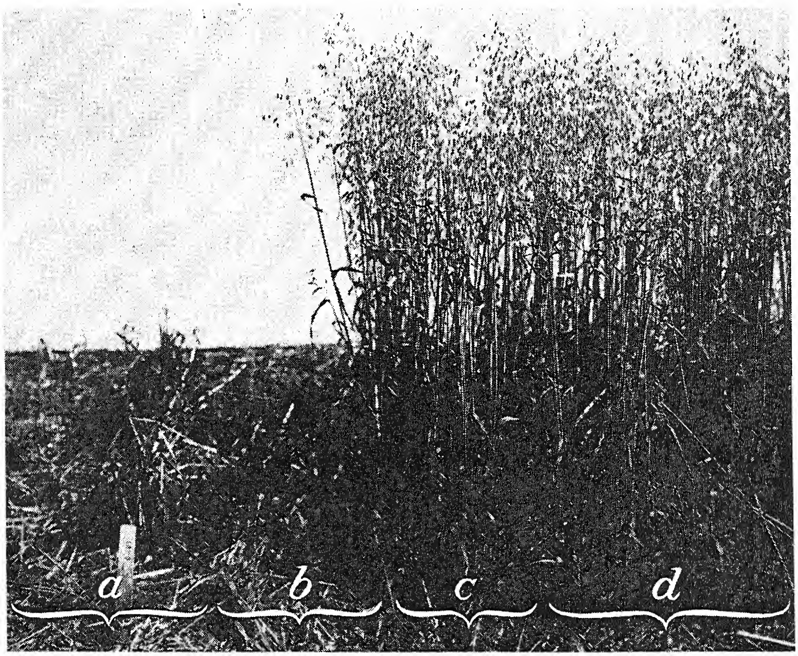

FIG. 1.—Result of both stem and crown rust infection on rows of parental lines and selections from the cross Markton × Rainbow at Ames, Iowa, in 1935. A, a selection from cross X311 (Markton × Iogold) × Carleton which proved susceptible to both rusts; B, Markton parent, susceptible to both rusts; C, Rainbow parent, resistant to both rusts; D, rows of selections resistant to both stem and crown rust.

tions of these crosses are presented in Table 5. The superiority of the Markton × Rainbow selections in this respect and the relationship between yield and test weight is evident. Test weights are particularly high among the selections from lines 684 and 708.

STRENGTH OF STRAW

Stiff straw, or the ability to resist lodging, is a major consideration in any oat breeding program. Frequently a stiff straw may determine the difference between success and failure of the crop. Observations on the standing ability of these selections were made at Ames and Kanawha, Iowa, in 1935, 1936, and 1937. Although most of these selections have given evidence of lodging resistance equal or superior to the nearest Iogold checks, only a few have remained standing in all tests. Selections which appear notable for stiff straw are as follows: Richland × Markton, selection 524–5; Markton × Iogold, selection 308–41576; and the Markton × Rainbow selections Nos. 708–2, 708–3, and 708–41974. The last three have resisted lodging in all tests, and selection No. 708–2 has a remarkably stiff straw for an oat so tall.

TABLE 5.—*Annual and average bushel weight of leading selections from four Markton oat crosses compared with Iogold.*

Selection or variety	C. I. No.	Bushel weight, lbs. Ames, Iowa 1936	Ames, Iowa 1937	Kanawha, Iowa 1935	Kanawha, Iowa 1936	Kanawha, Iowa 1937	Station years grown	Av. bu. wt., lbs.	Dev. from comp. av. of Iogold check, lbs.
				Richland×Markton (×2712)					
524–5	—	30.5	30.4	—	29.4	—	3	30.1	+5.3
–13	—	29.4	26.0	22.8	25.3	—	4	25.9	+2.2
588–6	—	26.2	27.2	19.9	19.9	26.3	5	23.9	–0.8
2411	3363	27.1	26.5	21.7	21.7	27.2	5	24.8	+0.1
2444	3364	26.7	28.9	20.7	23.2	28.7	5	25.6	+0.9
				Markton×Iogold (×2737)					
200–4	—	30.0	28.5	20.8	25.3	31.3	5	27.2	+2.5
–9	—	29.1	28.3	21.3	25.5	30.7	5	27.0	+2.3
–41481	—	29.3	29.3	—	24.7	30.3	4	28.4	+2.6
–41486	3509	30.4	27.1	—	26.3	30.0	4	28.5	+2.7
–41493	3510	29.6	28.2	—	26.0	29.1	4	28.2	+2.4
–41499	3352	29.1	27.0	—	25.6	27.8	4	27.4	+1.6
–41509	3353	28.7	26.5	—	26.0	29.4	4	27.7	+1.9
307–41530	3512	29.7	28.4	—	27.2	30.4	4	28.9	+3.1
–41534	—	28.6	27.8	—	26.7	28.7	4	28.0	+2.2
–41541	3513	28.9	27.1	—	27.1	30.1	4	28.3	+2.5
–41561	—	27.9	26.2	—	23.1	28.2	4	26.4	+0.6
308–2	—	30.0	27.2	20.8	25.5	30.7	5	26.8	+2.1
–3	3237	29.6	25.6	21.1	25.2	29.2	5	26.1	+1.4
–5	3239	28.7	—	23.2	24.5	—	3	25.5	+2.0
–41568	3356	28.9	26.6	—	26.5	29.5	4	27.9	+2.1
–41576	3357	29.3	30.1	—	27.2	31.8	4	29.6	+3.8
–41580	3358	29.4	27.2	—	26.5	30.4	4	28.4	+2.6
–41585	—	27.4	25.5	—	25.9	—	3	26.3	+1.5
310–41626	—	28.4	26.5	—	24.6	—	3	26.5	+1.7

TABLE 5.—*Concluded.*

Selection or variety	C. I. No.	Bushel weight, lbs. Ames, Iowa 1936	Ames, Iowa 1937	Kanawha, Iowa 1935	Kanawha, Iowa 1936	Kanawha, Iowa 1937	Station years grown	Av. bu. wt., lbs.	Dev. from comp. av. of Iogold check, lbs.
				Edkin×Markton (×2738)					
2586	—	29.8	26.8	19.3	23.8	29.0	5	25.7	+1.0
2588	3365	31.3	28.2	25.1	26.4	27.4	5	27.7	+3.0
				Markton×Rainbow (×2871)					
668	3241	29.5	29.5	23.8	24.6	32.2	5	27.9	+3.2
684–3	3341	31.4	31.2	27.3	27.9	34.1	5	30.4	+5.7
–5	3342	31.6	30.8	24.3	28.1	33.0	5	29.6	+4.9
–6	3244	29.0	30.6	28.4	28.2	33.9	5	30.0	+5.3
–9	3343	31.6	31.8	26.7	27.2	32.6	5	30.0	+5.3
–41913	—	29.3	29.1	—	27.8	31.9	4	29.5	+3.7
–41925	—	30.6	29.5	—	26.8	32.4	4	29.8	+4.0
–41944	3505	31.0	30.6	—	27.1	33.0	4	30.4	+4.6
708–2	3346	30.3	30.2	27.7	29.7	32.2	5	30.0	+5.3
–3	3247	30.9	30.8	26.6	30.2	33.3	5	30.4	+5.7
–41974	—	30.2	31.2	—	28.2	33.8	4	30.9	+5.1
–41975	—	29.2	30.9	—	27.8	33.7	4	30.4	+4.6
–41978	3506	32.0	32.0	—	27.2	33.8	4	31.3	+5.5
–41980	3507	30.7	30.2	—	28.3	33.2	4	30.6	+4.8
–41981	—	29.5	31.9	—	27.5	—	3	29.6	+4.8
–41983	3508	30.7	30.7	—	29.0	33.1	4	30.9	+5.1
709	3348	30.6	30.9	20.6	28.1	31.7	5	28.4	+3.7
1907	—	29.9	31.3	—	23.5	—	3	28.2	+3.4
1943	3350	30.7	30.7	27.5	24.9	32.9	5	29.3	+4.6
1965	3351	30.1	29.0	28.2	25.5	31.8	5	28.9	+4.2
1976	—	27.4	28.1	—	21.7	—	3	25.7	+0.9
1988	—	26.5	28.5	22.1	22.8	—	4	25.0	+1.3
2016	—	29.5	—	25.1	22.5	—	3	25.7	+2.2
Markton	2053	—	—	17.5	—	—	1	17.5	−2.9
Iogold	2329	27.2*	24.3*	20.4*	22.9*	28.8*	5	24.7	±0.0
Rainbow	2345	—	—	27.0	—	—	1	27.0	+6.6
Average all strains exclusive of checks		29.5	28.9	23.7	26.0	31.0	-	—	—

*Average of all checks.

DISCUSSION

The hybrid progenies in these crosses were handled by (1) the bulk method and (2) the pedigree selection method.

The bulk method consisted of sowing a few rod rows of each cross with seed produced the previous year. Selections usually were made in the F_4 ,F_5, or F_6 generations on the basis of rust resistance and other desirable plant characters. Thereafter the progenies were handled by the pedigree method. The bulk method was used exclusively in growing the early generations of the Edkin × Markton and Markton × Rainbow crosses and partly with the Markton × Iogold and Richland × Markton crosses.

The pedigree method consisted of selecting in each generation after the first until the strains appeared to be uniform. This entailed con-

siderable recording of data on each selection in the early generations. The method was used largely in the Markton × Iogold and Richland × Markton crosses.

Numerous strains were discarded usually on the basis of readily observable deficiencies such as disease susceptibility, weak straw, etc. Strains which appeared especially good otherwise but which seemed to be heterozygous for plant characters or for disease resistance were re-selected and these re-selections were tested for yield and other agronomic characters.

High-yielding selections were derived from the Richland × Markton and Markton × Iogold crosses by both breeding methods, and by the bulk method from the Markton × Rainbow and Edkin × Markton crosses. Both methods have advantages as well as limitations. The pedigree method is preferable from all viewpoints if funds are available and experimental conditions permit, but the time and expense involved in an extensive breeding program may make it prohibitive. The bulk method permits a large number of hybrids to be grown in early generations without great expense. Selections can be made in more advanced generations as time and space become available, and in the meantime natural forces presumably are eliminating the less desirable strains.

The bulk method of breeding is only partly suited to breeding for disease resistance. In a program where breeding for resistance to several diseases is being conducted simultaneously, the problem is exceedingly complex. It is often difficult to obtain resistance to several diseases, together with favorable agronomic characters, in one individual. In such a program the bulk method is extremely valuable in early generations but must be dispensed with in later generations in favor of the refinements of pedigree methods. The writers have found it advantageous to select first for the major characters desired and later to re-select for homozygosity among the minor characters, as was done in the Markton × Rainbow cross.

Why so few high-yielding selections were obtained from the Richland × Markton cross is puzzling. Only 18 F_2 plants were selected in that group handled by the pedigree method. Possibly some desirable plants were not apparent in that generation. This might seem a plausible explanation were it not true that 187 selections were made from the bulk material and of these comparatively few have been exceptional yielders. Richland itself is a high-yielding oat, and exceedingly productive progenies have been selected from several other crosses in which Richland was a parent. It would therefore seem likely that this Richland × Markton cross was one in which the parents did not combine successfully, i.e., "nick" sufficiently well for the production of exceptionally high-yielding progenies. In the Markton × Rainbow cross the excellent characters of both parents were combined successfully and many high-yielding selections resulted.

The original F_4 plant of line No. 708 of the Markton × Rainbow cross was selected from a bulk population because of rust resistance. Tests of its progenies proved them to be resistant to loose and covered smut and to certain races of crown rust as well as stem rust.

They produce very high yields of grain of high test weight and have tall, exceptionally stiff straw. Some of the re-selections of line No. 708 have not lodged more than 2% in tests in which comparable Iogold checks frequently were lodged 100%. The notable ability of Markton to yield well under hot, droughty conditions probably was inherited by many of the selections from this cross as indicated by data obtained in 1934 at Ames. The combining to a marked degree of so many favorable characters in a single individual is unusual.

SUMMARY

A definite program was initiated in 1927 for the breeding of oat varieties for north-central United States with resistance to stem rust and smut. The smut-resistant variety, Markton, was crossed with the rust-resistant varieties, Richland, Iogold, Edkin, Iowa 444, and Rainbow. Some 5,000 selections and re-selections were tested. These selections have been subjected repeatedly to inoculation with spores of loose smut, covered smut, stem rust, and crown rust, in the greenhouse and field. Some of the resistant selections have been advanced to yield tests in plats.

Many of the selections have been found to be resistant to stem rust, covered smut, and loose smut during several seasons. Some of the selections from the Markton × Rainbow cross also were resistant to certain races of crown rust. This resistance should afford adequate protection against crown rust in the Corn Belt in certain years. However, they lack resistance to other races of crown rust, which may reduce their value in other years.

Selections from the crosses Markton × Rainbow and Markton × Iogold have proved the most promising, and some of them offer exceptional possibilities as agricultural varieties. Results indicate that many of these selections are superior in yield not only to the parent varieties but also to the standard varieties grown in the Corn Belt. Some of these selections also are superior to standard varieties in bushel weight. The bushel weight of many selections from the Markton × Rainbow cross has averaged 3 to 5 pounds more than that of Iogold grown under similar conditions. Many of the Markton × Rainbow selections have exceptionally stiff straw. Some have yielded comparatively well under extremely droughty conditions. Some of the highest yielding selections from this cross are resistant to the smuts and rusts and in addition have stiff straw and a high bushel weight.

CRABGRASS IN RELATION TO ARSENICALS[1]

F. A. Welton and J. C. Carroll[2]

FOR many years statements pro and con have been made regarding the efficiency of lead arsenate as an agent for the control of crabgrass. Most of these statements were based on observation. Many observations by numerous people were possible because lead arsenate is in common use on golf courses and other places as an agent for the control of grubs. Observations at best, however, are not always dependable. If made under variable conditions or even if under comparable conditions but by different individuals, the possibility of arriving at erroneous conclusions is considerable.

To ascertain if lead arsenate has any merit as an agent for the control of crabgrass, experiments were conducted at the Ohio Agricultural Experiment Station during the period 1930–36, inclusive. Whether lead arsenate may prove to be an effective agent under all conditions remains to be determined. The results to date at Wooster, however, have been promising. It seemed advisable, therefore, at this time to make available the results thus far obtained in the hope that others might be stimulated to make trials to the end that its adaptation and usefulness on different types of soil and under varying conditions might be the more speedily determined. Moreover, the effectiveness of lead arsenate as an agent of control for the Japanese beetle is already accepted and since the presence of this pest is now (1938) recognized in Ohio, any information, particularly with reference to the aftereffect of the arsenates on the desirable turf grasses, is timely.

PRELIMINARY EXPERIMENT

As a preliminary test a single plat, 5 by 20 feet, on the Station campus was treated with lead arsenate July 25, 1930, at the rate of 35 pounds per 1,000 square feet. To facilitate even distribution, the arsenate was first mixed with compost, half-and-half. No injury was observable to the plants that year. In the following summer, 1931, which was a favorable season for crabgrass, it was early apparent that a relatively small number of plants was appearing on the treated plat. On September 14, after the plants had changed color and the identity of individuals, therefore, was the more easily discernable, a count showed a total of 75 on the 100 square feet, 23 of which were close to the margin, where in distributing the arsenate, the workers intuitively shy away lest some of the material be thrown beyond the bounds of the plat. Including the border plants, the reduction amounted to 94.6%, for on an equal area adjoining there were 1,350 plants. The number of crabgrass plants found on this plat in subsequent years, *viz.*, 1932, 1933, 1934, 1935, and 1936, was 52, 51, 14, 28, and 48, respectively. The control on a percentage basis for the same years in the order named was 98.2, 97.1, 97.6, 95.8, and 97.1.

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication June 29, 1938.

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TIME AND RATE OF APPLICATION

1931–32 RESULTS

In the following season a second test was started and was so enlarged as to yield information regarding the time and rate at which the lead arsenate should be applied. The test was conducted in a private lawn in the community which was only fairly satisfactory for such a test because the stand of crabgrass plants was not dense and was less uniform on some parts than on others. The lead arsenate was applied at the rates of 2.5, 5, 10, 20, and 40 pounds per 1,000 square feet. Applications at these rates were made October 22 and December 11, 1931, and February 19, April 29, and June 6, 1932. The plats were 4 by 25 feet.

On account of lack of uniformity in stand of plants before treatment, no attempt was made to count the plants in the fall of 1932. From the lighter applications, 2.5 and 5 pounds, the effect, if any, was not discernible. From the heavier rates, 20 and 40 pounds, particularly the latter, however, the control was very marked. From the appearance of these plats the completeness of the elimination was satisfactory. The results from the application made on the first four dates were quite uniform.

1932–33 RESULTS

In the fall of 1932 and before the dying crabgrass had disappeared, an area was selected on the Station campus, all of which had been badly infested that year with crabgrass. Of course, it will be understood that over any large area there is usually considerable variation in the stand of such plants.

Lead arsenate was applied at the rates of 10, 15, 20, 25, 30, 35, and 40 pounds per 1,000 square feet on each of five dates *viz.*, October 31 and December 27, 1932, and February 15, April 21, and June 22, 1933. The plats were 5 by 10 feet and the various series joined each other. Counts were made in October 1933, 1934, and 1935, and the results, expressed in terms of plants per 1,000 square feet are given in Table 1.

These counts show that the lead arsenate was effective. The first year, 1933, the degree of control did not vary greatly with the first three dates of application. In general, the April application was somewhat less effective than the earlier ones. The June treatment was a complete failure, probably because the crabgrass was already up when the material was put on. In subsequent years, however, the June application also was effective as shown by the counts in the same table for the years 1934 and 1935.

The degree of control varied with the rate of application. With each increment of lead arsenate, up to and including 25 pounds, there was in general a progressive decrease in number of crabgrass plants. Beyond 25 pounds the effectiveness did not increase materially.

The higher counts in 1933 and 1935 than in 1934 were probably due to unusually dry weather in the early part of 1934. For the 8-week period, May 1 to June 25 inclusive, the time during which the

TABLE 1.—*Number of crabgrass plants per 1,000 square feet after treatment with lead arsenate at different times and rates, 1932–33.*

Time of application	Pounds of lead arsenate per 1,000 square feet								
	Check	10	15	20	25	30	35	40	Average of all rates
				October, 1933					
Oct., 1932...	15,080	1,920	360	220	120	260	280	260	489
Dec., 1932..	15,880	4,340	980	620	340	240	280	160	994
Feb., 1933..	15,200	640	360	520	200	300	140	160	331
Apr., 1933..	15,290	1,400	680	1,300	860	760	540	740	897
June, 1933..	15,000	20,440	18,440	17,380	15,020	17,100	14,040	11,340	16,251
Average*	15,362	2,075	595	665	380	390	310	330	—
				October, 1934					
Oct., 1932...	1,320	280	160	20	20	0	20	80	83
Dec., 1932..	1,600	1,000	320	0	20	40	20	0	200
Feb., 1933..	1,440	200	40	20	0	0	0	20	40
Apr., 1933..	1,760	100	40	40	0	0	20	20	31
June, 1933..	1,960	140	120	120	40	20	40	100	83
Average	1,616	344	136	40	16	12	20	44	—
				October, 1935					
Oct., 1932...	3,250	220	280	60	40	0	20	120	106
Dec., 1932..	2,470	1,960	860	180	20	0	60	0	440
Feb., 1933..	2,550	260	20	20	0	20	0	0	46
Apr., 1933..	3,280	340	60	100	20	100	20	160	114
June, 1933..	3,470	1,120	340	360	180	160	120	160	349
Average....	3,004	780	312	144	52	56	44	88	—

*Exclusive of June application.

majority of crabgrass seeds normally germinate in the latitude of Wooster, the rainfall in 1934 was 46.0 and 30.7% of that for the same period in 1933 and 1935, respectively.

1933–34 RESULTS

On another area of the Station campus also badly infested with crabgrass lead arsenate was applied in 1933–34 at the same rates as in the preceding year. In this test the dates of application were October 26 and December 20, 1933, and February 15, April 16, and June 11, 1934. The plats were 5 by 5 feet and the five series joined each other. In October 1934 and again in 1935 counts were made and the results, expressed in terms of plants per 1,000 square feet, are given in Table 2.

In this as in the three preceding tests, lead arsenate was effective in controlling crabgrass. The results as regards both time and rate of application were in general agreement with those obtained from the 1932–33 applications (Table 1). The generally lower counts in 1934 than in 1935 may have been due to more favorable seasonal conditions for the growth of crabgrass in the latter than in the former year. In October 1935, after the crabgrass plants were dead, they were re-

TABLE 2.—*Number of crabgrass plants per 1,000 square feet after treatment with lead arsenate at different times and rates, 1933–34.*

Time of application	Pounds of lead arsenate per 1,000 square feet								
	Check	10	15	20	25	30	35	40	Average of all rates
					October, 1934				
Oct., 1933...	6,600	1,080	680	320	280	200	160	0	389
Dec., 1933..	1,760	320	360	200	160	0	40	160	177
Feb., 1934..	7,440	3,640	600	120	320	200	160	80	731
Apr., 1934..	2,320	560	680	120	80	40	320	240	291
June, 1934..	7,460	5,280	1,880	760	1,000	400	120	280	1,389
Average* ...	4,530	1,400	580	190	210	110	170	152	—
					October, 1935				
Oct., 1933...	6,340	2,480	1,240	1,360	680	880	400	440	1,069
Dec., 1933..	4,460	1,000	440	0	160	80	0	120	257
Feb., 1934..	5,820	3,320	2,280	1,280	520	440	160	80	1,154
Apr., 1934..	5,080	80	600	480	440	480	320	480	411
June, 1934..	4,460	680	1,080	600	440	440	280	400	560
Average....	5,232	1,512	1,128	744	448	464	232	304	—

*Exclusive of June application.

moved from each treated and from an adjoining untreated plat (5 by 5 feet) in several series. The effectiveness of the different rates of application in a fairly representative series, the one treated October 26, 1933, is shown in Fig. 1.

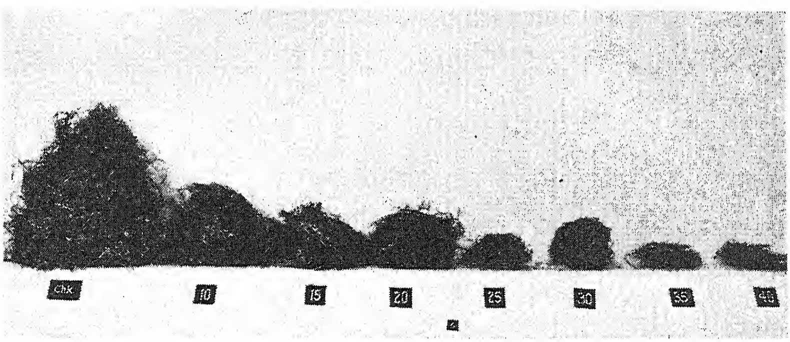

FIG. 1.—Quantity of crabgrass remaining on plats (5 by 5 feet) untreated (left) and treated with lead arsenate at the rates of 10, 15, 20, 25, 30, 35, and 40 pounds per 1,000 square feet.

MANNER OF APPLICATION

In the preceding tests the lead arsenate was first mixed with soil, half-and-half, in order to facilitate even distribution. To compare the efficiency of this with other methods, a test was started in the fall of 1932 in which the lead arsenate was applied in three different ways, namely, (1) as a mixture with soil, half-and-half; (2) as a dust; and

(3) as a spray. In each of these three tests the lead arsenate was applied at four different rates, namely, 5, 10, 20, and 40 pounds per 1,000 square feet. In the fall of 1933 and again in 1935 a count of the crabgrass plants was made on each of the treated plats and on an adjoining untreated plat.

The counts, recorded in Table 3, show no consistent superiority for any method in either year. Apparently, the important factor is that the material be thoroughly and evenly distributed.

TABLE 3.—*Manner of application of lead arsenate use at different rates.*

Pounds of lead arsenate per 1,000 sq. ft.	Number of plants per 1,000 square feet							
	1933				1935			
	Check	Mixture	Dust	Spray	Check	Mixture	Dust	Spray
5	—	3,180	3,140	2,400	—	1,360	1,240	500
10	—	600	2,000	1,000	—	260	880	780
20	—	380	360	520	—	320	160	440
40	—	160	100	300	—	0	60	60
Average of all rates	8,880	1,080	1,400	1,055	3,250	485	585	445

IN MIXTURE WITH VARIOUS PROPORTIONS OF SOIL

In order to determine if the efficiency in application of lead arsenate might be augmented through the use of increasing quantities of soil, an experiment was started in the fall of 1933 in which the lead arsenate was mixed with soil in the proportion of 1, 3, 5, 7, and 9 times its weight. The arsenate, mixed in these proportions, was applied at the rate of 5, 10, 20, and 40 pounds per 1,000 square feet. The plats were 5 by 5 feet. The crabgrass plants on these and on adjoining check plats were counted in the fall of 1934 and again in 1935. The counts are tabulated in Table 4.

The results reveal no consistent increase in degree of control as the proportion of soil was augmented. If the material is carefully distributed the proportion of soil is probably not important.

KINDS OF ARSENATE

By way of comparison with lead arsenate calcium arsenate was included in the test in the fall of 1933. The calcium arsenate was applied at the same time and rates and in the same manner as was the October treatment of lead arsenate. The two series of plats parallelled each other.

This test was repeated on the Station campus in 1935 and again in 1936. In the fall of 1935 manganese arsenate was included. The details of application of it were the same as for the other two arsenates. All three were applied November 20. In the fall of 1936 arsenic pentoxide was substituted for the manganese arsenate. The three materials were applied November 25. All the plats each year were the same size, 5 by 5 feet.

TABLE 4.—*Lead arsenate mixed with soil in different proportions and applied at different rates.*

Pounds of lead arsenate per 1,000 sq. ft.	Number of crabgrass plants per 1,000 sq. ft.					
	Check	1 to 1	1 to 3	1 to 5	1 to 7	1 to 9
			1934			
5	7,280	4,560	2,760	5,480	7,080	4,360
10	5,720	960	960	800	1,400	1,160
20	4,180	280	80	0	40	40
40	2,600	000	80	40	40	40
Average	4,945	1,450	970	1,580	2,140	1,400
			1935			
5	7,340	7,200	4,960	7,160	6,280	4,880
10	7,000	1,840	760	1,240	1,520	1,160
20	4,980	480	80	120	0	0
40	3,540	80	40	40	40	40
Average	5,715	2,400	1,460	2,140	1,960	1,520

The number of crabgrass plants in each test a year following treatment and the 3-year average of the calcium and lead arsenates are shown in Table 5.

TABLE 5.—*Number of crabgrass plants per 1,000 square feet after treatment with different arsenates.*

Kinds	Pounds of arsenate per 1,000 sq. ft.								
	Check	5	10	15	20	25	30	35	40
			October, 1934 (Treated in 1933)						
Calcium arsenate	6,220	—	1,280	160	200	40	0	0	0
Lead arsenate	6,600	—	1,080	680	320	280	200	160	0
			October, 1936 (Treated in 1935)						
Calcium arsenate	14,780	1,880	200	120	0	0	—	—	—
Lead arsenate	13,660	3,280	1,560	2,480	1,040	880	—	—	—
Manganese arsenate	12,660	2,400	320	160	120	0	—	—	—
			October, 1937 (Treated in 1936)						
Calcium arsenate	7,940	3,760	3,000	2,000	640	680	—	—	—
Lead arsenate	6,520	6,640	4,320	2,040	1,240	1,160	—	—	—
Arsenic pentoxide*	7,480	4,760	3,160	1,240	520	360	—	—	—
			3-year Average, 1934–37						
Calcium arsenate	9,647	—	1,493	760	280	240	—	—	—
Lead arsenate	8,927	—	2,320	1,733	867	773	—	—	—

*Quantities applied equivalent in arsenic to that contained in the lead arsenate.

From these results the conclusion may be drawn that calcium arsenate, pound for pound, is more effective than lead arsenate as an agent for the control of crabgrass. Unfortunately, at the heavier rates, it injured severely and even killed much of the grass. The dam-

age, however, did not become apparent until about a year later. The highest rate of application at which no killing was observable 2 years after application was 15 pounds per 1,000 square feet. At this rate of application, the control was as good as from the use of 25 pounds of lead arsenate.

The 1-year test with manganese arsenate indicated that it is somewhat less effective than calcium but more effective than lead arsenate.

Arsenic pentoxide was effective, but in the heavier rates which were required to give satisfactory control it killed all the grass.

AFTEREFFECT OF ARSENATES

All the arsenates discolored the grass somewhat. The discoloration, however, did not become apparent until a year or more after application and was most noticeable in winter. The lead arsenate, even in the larger quantities, did not cause the development of any bare spots in the turf. On the other hand, calcium arsenate, in quantities exceeding 15 pounds per 1,000 square feet burned severely and even killed much of the grass.

That the discoloration was accompanied by a reduction in growth of grass, at least in the case of the lead arsenate, was shown by the growth of grass obtained on them in 1934 and again in 1935. In these years the green clippings from the plats treated in October, December, and February, 1932–33, and from three equal adjoining untreated areas were weighed. The results, expressed in terms of pounds per 1,000 square feet, are recorded in Table 6.

TABLE 6.—*Aftereffect on Kentucky bluegrass of lead arsenate treatments for crabgrass.*

Pounds of grass, green weight, per 1,000 square feet								Percentage of normal growth
Oct. 31, 1932		Dec. 27, 1932		Feb. 15, 1933		Av. three dates		
Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	
1934								
110	160	78	107	64	95	84	121	69
1935								
322	393	198	247	168	216	229	285	80

From the yields it may be noted that the growth, on the average, amounted on the treated areas to 69 and 80% of that on the untreated areas in 1934 and 1935, respectively. These figures are subject to some error due to the presence of more crabgrass on the untreated than on the treated areas. This discrepancy, however, was not great, especially in 1934, for in that year the growth of crabgrass was sparse on account of drouth.

In 1935 the details of harvesting were so modified as to reveal the effect of the different rates of application individually. The weights are given in Table 7.

TABLE 7.—*Aftereffect on Kentucky bluegrass of lead arsenate applied at different rates.*

Pounds of lead arsenate per 1,000 sq. ft.	Pounds of grass, green weight, per 1,000 sq. ft.								Per cent of normal growth
	Oct. 31, 1932		Dec. 27, 1932		Feb. 15, 1933		Av. three dates		
	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	Lead arsenate	No lead arsenate	
10	355	384	244	282	190	210	263	292	90.1
15	327	434	208	248	175	214	237	299	79.3
20	321	421	189	243	155	213	222	292	76.0
25	301	399	192	252	149	217	214	289	74.0
30	329	364	199	239	170	225	233	276	84.4
35	332	404	178	220	164	217	225	280	80.4
40	292	347	177	242	174	213	214	267	80.1

The yields show that the lead arsenate reduced the growth in every one of the seven triplicate applications, 21 comparisons altogether. On the average, the plats which received the least lead arsenate made 90.1% of normal growth. On all the others the reduction was greater. Contrary to expectations, however, it did not decrease consistently as the rate of application of lead arsenate increased.

RECOVERY FROM AFTEREFFECT

FERTILIZATION

To determine if the recovery of grass injured by lead arsenate can be hastened through the use of fertilizer, one-half of each of the plats arsenated in 1932–33 was top-dressed with fertilizer. Poultry peat[3], Nitrophoska, and a 10–6–4 were used on the October, December, and February groups, respectively. The poultry peat was supplied at the rate of 200 pounds per 1,000 square feet (5 pounds nitrogen); the Nitrophoska (15–30–15) and the 10–6–4, each at the rate of 10 pounds per 1,000 square feet. One-half of each of the unarsenated or "check" plats were also fertilized with the same kinds and quantities of materials as were used on the arsenated areas. The top-dressings were made October 30, 1933, and April 23, 1935. During the season of 1934 the grass was cut and weighed in four parts as follows: (1) No treatment, (2) lead arsenate alone, (3) lead arsenate plus fertilizer, and (4) fertilizer alone. The results, expressed in pounds per 1,000 square feet green weight, are shown graphically in Fig. 2. The graphs show clearly that all the fertilizers revived the growth of grass to a point as good or better than that on the untreated area. Poultry peat

[3]A mixture resulting from the use of peat as litter in poultry houses, later dried and pulverized.

was the most effective, probably because it carried more nitrogen than did either of the other two fertilizers. Moreover, it was the only one of the three which restored the grass to its normal shade of green. The graphs show also that lead arsenate reduced the growth on the fertilized as well as on the unfertilized area.

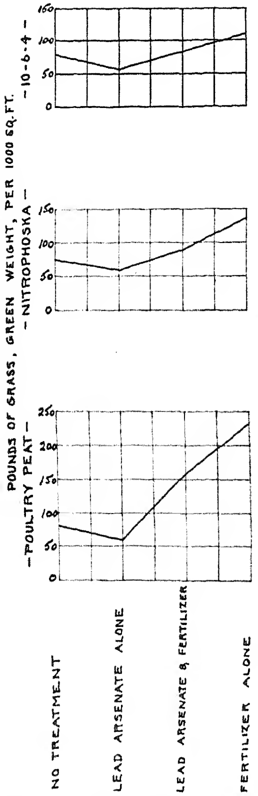

FIG. 2.—Effect of lead arsenate on the growth of grass.

LIMESTONE

On one area of the Station campus treated with lead arsenate October 31, 1932, and top-dressed with limestone and superphosphate October 30, 1933, the chlorosis of the grass was less marked than on an adjoining arsenated but unfertilized and unlimed area. In this connection it should perhaps be added that on a Wooster lawn treated with arsenate January 7, 1935, the degree of control obtained was somewhat less than that on the Station campus. This city lawn adjoined an oiled limestone street. The reaction of the soil was pH 6.7; whereas that of the Station campus where good control was obtained was pH 5.8. Possibly, the effectiveness of lead arsenate as an agent for the control of crabgrass is related to the limestone content of the soil.

DISTRIBUTION OF ARSENIC IN SOIL

In view of the injury to the grass an attempt was made to ascertain the distribution of the arsenic through the soil. Accordingly, in 1935, soil samples were taken in 1-inch horizons to a depth of 10 inches on the plats treated in 1930, 1931, 1932, 1933, and 1934. In three of the years, 1931, 1932, and 1933, samples were taken from plats to which lead arsenate had been applied at three rates, *viz.*, 10, 20, and 40 pounds, per 1,000 square feet, and in the others at one rate only. The rate or rates of application in each of the 5 years and the total arsenic found in each horizon expressed in terms of elemental arsenic per 1,000 square feet, are shown in Table 8.

If it is assumed that all the arsenic found came from that added as lead arsenate, then it can be seen from Table 8 that a part of the arsenic had penetrated the soil and that the larger the quantity applied, the greater the depth to which it had reached. In one case, 7.8 pounds of elemental arsenic applied in 1933–34 had penetrated at least 10 inches. The total amount found showed that some loss had occurred from each application. The heavier the application, the greater was the loss. Furthermore, from comparable plats it may be seen that the loss increased in general as the period of contact was extended. In this comparison the 1935 application was not included

TABLE 8.—*Pounds of elemental arsenic per 1,000 square feet recovered in 1935.*

Soil horizon, inches	Pounds of elemental arsenic per 1,000 square feet originally applied										
	1930 (campus)	1931–1932 (Martin yard)			1932–1933 (campus)			1933–1934 (campus)			1935 (watering plat)
	6.82	1.95	3.90	7.80	1.95	3.90	7.80	1.95	3.90	7.80	3.90
1	2.14	0.39	1.15	2.12	0.50	1.52	3.00	1.26	2.03	2.27	1.66
2	1.29	0.18	0.68	1.42	0.11	0.20	1.19	0.31	0.56	1.06	0.33
3	0.53	0.08	0.38	0.95	0.04	0.25	0.46	0.06	0.32	0.86	0.30
4	0.27	—	0.19	0.45	—	0.20	0.18	0.03	0.24	0.44	0.14
5	0.19	—	0.04	0.16	—	0.19	0.10	—	0.22	0.43	0.17
6	0.11	—	—	0.04	—	0.12	0.06	—	0.17	0.34	0.25
7	0.03	—	—	0.01	—	0.12	0.03	—	0.07	0.23	0.04
8	—	—	—	—	—	0.06	—	—	—	0.16	0.03
9	—	—	—	—	—	0.02	—	—	—	0.14	—
10	—	—	—	—	—	—	—	—	—	0.03	—
Total......	4.56	0.65	2.44	5.15	0.65	2.68	5.02	1.66	3.61	5.96	2.92
Recovered, %......	66.8	33.3	62.6	66.0	33.3	68.7	64.3	85.1	92.6	76.4	74.9
Lost, %...	33.2	66.7	37.4	34.0	66.7	31.3	35.7	14.9	7.4	23.6	25.1

because it was not comparable on account of artificial watering. The percentage of loss from all applications, including the different rates, is shown at the bottom of Table 8.

On the soil samples taken from the single application made in 1930 and 1935 and on the ones representing the heaviest rate, 7.8 pounds per 1,000 square feet in 1931, 1932, and 1933, the water-soluble arsenic was determined. The results expressed in pounds of elemental arsenic per 1,000 square feet for each of the 10 horizons and for the 5 years are shown in Table 9. In no case was soluble arsenic found below the fourth inch.

The situation with reference to soluble arsenic in the upper 2 inches correlates closely with the appearance of the turf. The chlorosis of the grass which formerly was apparent on the plats treated in 1930 and 1931 has practically disappeared. On the plats treated in 1932 and 1933, chlorosis is still (1937) plainly visible. On the plat treated in 1935 the discoloration has never been very perceptible, probably because of the lighter application and in part perhaps because of the leaching from the artificial watering.

SUMMARY

1. Lead arsenate as an agent for the control of crabgrass proved to be effective in each of the 6 years it was used.

2. Applications made in October, December, February, and April were effective. Applications made in June were not effective the first

TABLE 9.—*Pounds of water-soluble elemental arsenic per 1,000 square feet found at different levels.*

Soil horizon, inches	1930 (campus)	1931–32 (Martin yard)	1932–33 (campus)	1933–34 (campus)	1935 (watering plat)
1	—	—	0.31	0.15	—
2	—	—	0.07	0.11	0.18
3	0.06	0.28	0.40	0.35	0.22
4	0.07	0.08	—	0.21	0.14
5	—	—	—	—	—
6	—	—	—	—	—
7	—	—	—	—	—
8	—	—	—	—	—
9	—	—	—	—	—
10	—	—	—	—	—
Total........	0.13	0.36	0.78	0.82	0.54

year but were in subsequent years. The crabgrass seedlings were in evidence at the time of the June application.

3. The rate of application ranged from 2.5 to 40 pounds per 1,000 square feet. From 20 to 25 pounds per 1,000 square feet usually gave almost complete control. Heavier rates increased the effectiveness little, if any. Lighter rates were noticeably less effective.

4. The lead arsenate was equally effective whether applied (1) in mixture with soil, (2) as dust, or (3) as spray. The proportion of soil to arsenate did not affect materially the degree of control.

5. Calcium arsenate, pound for pound, was more effective than lead arsenate; 15 pounds per 1,000 square feet of the former giving practically as good results as 25 pounds of the latter. Calcium arsenate, however, injured and in fact killed some of the grass when used in quantities heavier than 15 pounds per 1,000 square feet. The action of manganese arsenate was more nearly like that of calcium than of lead arsenate. The use of arsenic pentoxide proved impractical for even in moderate quantities it killed the desirable grasses.

6. Lead arsenate injured the grass somewhat. The brownish appearance did not appear until a year or more after application. The quantity of growth was reduced 31 and 20% the second and third years, respectively, after treatment.

7. The bad aftereffect from the use of lead arsenate was overcome by the liberal use of fertilizers rich in nitrogen. The addition of limestone also improved the appearance of the grass.

8. Analyses of the soil showed that with the heaviest rate of application the arsenic had penetrated to a depth of at least 10 inches. Even with the heaviest rates of application no water-soluble arsenic was found at a greater depth than 4 inches.

FERTILIZING CONSTITUENTS OF COTTON BURS OR COTTON BUR ASHES AND THEIR EFFECT ON CROP YIELDS[1]

Horace J. Harper, Harley A. Daniel, and Garth W. Volk[2]

CONSIDERABLE data (8, 10, 12, 13)[3] have been published on the chemical composition of cotton plants, but little information is available concerning the fertilizing value of the burs and their ashes. Fraps (6) states that where yields of 1,000 to 1,200 pounds of seed cotton per acre are produced, the amount of burs for each 300 pounds of seed is about 160 pounds. McBryde (9) found that 14.21% of a mature dry cotton plant is burs. More than 50% of the cotton in western Oklahoma is harvested by snapping, consequently large quantities of burs accumulate at the gins during the ginning operations. The disposal of this material depends upon local conditions and many inquiries are received annually concerning the utilization of the ash. If the burs are not burned, they are usually scattered on fields near the gins and the rate of application in tons per acre is usually high.

EXPERIMENTAL PROCEDURE

The effect on the yield of seed cotton of applying cotton burs and their ashes to Kirkland soil has been studied since 1926 at Oklahoma Agricultural Experiment Station. This soil contains about 2,000 pounds of total nitrogen per acre in the surface 6⅔ inches which is higher than the average nitrogen content of the upland soils where cotton is usually planted. The burs were applied at intervals of 3 years on different plats at rates of 3 and 6 tons per acre, respectively, except during the first season, when the rate was 1 and 3 tons per acre. On one series of plats the treatments were applied before the land was plowed. In order to study the effect of different methods of application, burs were scattered over the surface of plowed land on adjacent plats and disked into the soil. Two plats were also treated in a similar manner with ashes equivalent to 3 and 6 tons of burs per acre.

Cotton burs were collected during the fall of 1937 from several counties in Oklahoma, and all seed, lint, and trash were removed. The samples were finely ground in a Wiley mill, oven dried at 105° C, and analyzed for total ash, nitrogen, phosphorus, and calcium by methods recommended by the Association of Official Agricultural Chemists. Magnesium was determined by a method recommended by Dean and Truog (3) and potassium by the sodium cobaltinitrite method (11).

[1]Contribution from the Department of Agronomy, Oklahoma Agricultural Experimental Station, Stillwater, Okla. Received for publication July 1, 1938.

[2]Professor of Soils, Assistant Agronomist, and Assistant Professor of Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 831.

RESULTS OF EXPERIMENTS

EFFECT OF COTTON BURS AND THEIR ASHES ON YIELD OF SEED COTTON

The fertilizing value of cotton burs and their ashes on the yield of seed cotton was studied and the results are recorded in Table 1. Although the seasons from 1934 to 1937 were very unfavorable for the production of cotton, the average increases in yield are significant. Ashes from an equivalent amount of burs only produced about one-half as great an increase in yield as the burs. Crop residues returned to the soil provide more favorable conditions for absorption and retention of water and have a desirable effect on tilth. In addition, the nitrogen they contain is available for plant use after decomposition has occurred. The combined effect of these factors should be recognized in order to explain the increased yield received from the burs. Three tons of burs applied at intervals of 3 years, either plowed or disked into the soil, give as good returns as 6 tons on adjacent plats treated in a similar manner. The average increase in yield was 189 pounds of seed cotton per acre when the light application was plowed under and 166 pounds when disked into the soil. The highest average gain from the heaviest treatment was 170 pounds per acre. These tabulations show that the light rate of fertilization was slightly more effective than the heavy treatment during this period. Cotton burs reduce the available nitrogen content of soil for a considerable period after they are applied (5); consequently, crops requiring a large amount of available nitrogen may suffer if planted before these residues have decayed sufficiently to narrow the carbon-nitrogen ratio to a point where nitrates can accumulate in the soil.

Results from a heavy application of ashes are slightly less than those obtained from the lighter treatment. The average increase in yield from the ashes from 3 tons of burs applied at intervals of 3 years was 75 pounds of seed cotton per acre and that from 6 tons treated in a similar manner, 61 pounds. Since the soil on the Oklahoma Agricultural Experiment Station farm does not give much response from potash fertilization, the results of this experiment might be considerably different if conducted on a soil deficient in available potassium.

COMPOSITION OF COTTON BURS AND THEIR ASHES

In order to secure information on the chemical composition of cotton burs and their ashes, 33 samples from 22 counties in Oklahoma were analyzed and the results recorded in Table 2. Some burs contained twice as much calcium, nitrogen, and total ash, and three times as much phosphorus and potash as other samples, while magnesium varied less than any other element. The average potassium content was higher than that obtained by other investigators (4, 5). The wide variation in the composition of this material is probably due to several factors, such as difference in soil, climatic conditions, and variety. The soils in the different areas from which these burs were obtained vary greatly in ferrility (1, 7), and this condition may be responsible for a part of the difference occurring in the composition

TABLE 1.—*The effect of cotton burs and their ashes on the yield of seed cotton at Stillwater, Oklahoma.*

Plat No.	Treatment and rate of application per acre*	Pounds of seed cotton per acre											Average, lbs. per acre	
		1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	Yield	Increase in yield
1 and 5	None	1,450	1,520	940	190	590	1,015	910	242	127	10	290	662	—
2	Ashes from 3 tons of burs†	1,820	1,730	1,100	180	660	1,080	780	272	174	30	284	737	75
3	3 tons of burs†	1,950	2,130	1,050	240	660	1,320	1,000	296	196	28	244	828	166
4	3 tons of burs‡	2,000	2,080	1,040	250	780	1,270	1,100	324	186	31	300	851	189
6 and 10	None	1,510	1,645	940	210	710	790	980	238	165	19	245	677	—
7	Ashes from 6 tons of burs†	1,670	1,700	1,180	200	800	880	920	264	200	32	268	738	61
8	6 tons of burs†	1,925	2,300	1,070	260	740	1,160	1,080	260	200	46	274	847	170
9	6 tons of burs‡	1,860	1,620	1,115	260	800	1,220	1,100	336	250	44	388	817	140

*Thirteen tons of cotton burs or the equivalent amount of ashes per acre have been applied to plats 2, 3, and 4, and 27 tons to plats 7, 8, and 9. One ton was added to the former and 3 tons to the latter in 1926, while the treatment was 3 and 6 tons, respectively, during the fall of the following seasons: 1927, 1930, 1933, and 1936.

†Applied on plowed land and disked into the soil.

‡Plowed into the soil.

TABLE 2.—*The composition of cotton burs and their ashes.*

Sample No.	County	Percentage of ash and nutrients in burs						Percentage of elements in ash			
		Ash	N	P	Ca	K	Mg	P	Ca	K	Mg
1	Beckham	11.02	0.76	0.07	0.69	5.74	0.22	0.60	6.26	52.08	2.00
2	Caddo	9.75	0.77	0.07	0.66	4.97	0.26	0.70	6.80	50.93	2.66
3	Carter	7.22	0.99	0.08	0.65	3.16	0.28	1.05	9.05	43.78	3.93
4	Choctaw	5.93	0.72	0.13	0.51	2.86	0.22	2.24	8.58	48.16	3.71
5	Cleveland	10.75	0.93	0.09	0.83	4.12	0.34	0.83	7.70	38.30	3.14
6	Coal	7.71	1.06	0.07	0.54	3.75	0.28	0.87	7.01	48.72	3.60
7	Coal	8.02	1.11	0.17	0.64	3.66	0.29	2.15	8.01	45.68	3.60
8	Cotton	10.74	1.07	0.08	1.02	4.46	0.34	0.79	9.53	41.52	3.15
9	Greer	10.52	0.87	0.07	0.79	5.02	0.26	2.16	7.53	47.79	2.51
10	Harmon	11.55	1.17	0.15	0.80	5.71	0.28	1.27	6.91	49.46	2.44
11	Hughes	5.93	1.05	0.08	0.48	2.61	0.22	1.38	8.15	44.00	3.68
12	Jackson	8.14	0.95	0.08	0.80	3.14	0.24	1.00	9.84	38.75	2.78
13	Jefferson	7.95	1.00	0.08	0.71	2.38	0.25	0.96	8.97	29.85	3.16
14	Jefferson	7.00	1.05	0.07	0.68	2.28	0.23	1.05	9.75	32.50	3.33
15	Kingfisher	8.58	1.40	0.12	0.81	3.42	0.28	1.43	9.43	39.81	3.31
16	Kiowa	10.67	0.97	0.11	0.83	5.07	0.30	1.04	8.07	47.49	2.85
17	Lincoln	10.27	0.78	0.09	0.61	3.79	0.28	0.91	5.95	37.53	2.77
18	McIntosh	6.70	1.33	0.21	0.61	2.25	0.29	1.43	9.07	33.63	4.31
19	Muskogee	6.12	1.31	0.12	0.52	2.07	0.23	2.04	8.42	33.83	3.76
20	Payne	13.09	1.27	0.15	0.86	6.25	0.27	1.18	6.56	47.77	2.06
21	Payne	9.92	1.07	0.08	0.67	5.12	0.23	0.77	6.71	51.60	2.30
22	Payne	9.98	1.25	0.10	0.70	2.65	0.21	1.00	6.99	26.50	2.06
23	Payne	12.03	1.30	0.09	0.72	2.31	0.23	0.85	6.58	19.20	2.13
24	Tillman	9.35	1.01	0.11	0.74	3.51	0.28	1.22	7.86	37.52	2.96
25	Tulsa	4.98	1.25	0.11	0.44	1.88	0.19	2.15	8.86	37.80	3.73
26	Wagoner	11.16	1.25	0.11	0.55	1.60	0.20	0.99	4.90	16.00	1.82
27	Wagoner	7.07	1.24	0.08	0.50	1.42	0.20	1.18	7.06	20.10	2.89
28	Wagoner	8.07	1.16	0.10	0.51	1.67	0.22	1.23	6.40	20.70	2.64
29	Wagoner	8.43	1.13	0.10	0.59	1.72	0.21	1.10	7.00	20.30	2.57
30	Washita	9.12	1.38	0.12	0.75	4.19	0.28	1.32	8.22	45.92	3.06
31	———	9.97	1.01	0.09	0.67	4.90	0.30	0.88	6.72	49.15	3.05
32	———	10.36	0.88	0.08	0.70	4.18	0.28	0.79	6.79	40.49	2.70
	Average	8.73	1.04	0.10	0.65	3.39	0.25	1.17	7.44	37.48	2.87
	Average as oxides	——	——	0.23	0.91	4.08	0.41	2.68	10.41	45.15	4.76

of the samples. Since drought decreases the phosphorus content of alfalfa and prairie hay and since calcium seems to increase under such conditions (2), it is quite probable that cotton burs produced on the same field during different seasons or during the same season may vary in composition.

The amount of each element in the cotton bur ashes was calculated from the percentage of total ash in the dry material. From a fertilizer standpoint, the most important constituent in the ash is potassium. The percentage of this element ranged from 16.00 to 52.08 in various samples. The average percentage was 37.48, which is almost as high as the potassium content of commercial grades of high potash fertilizers. In addition to this very valuable ingredient, there were considerable quantities of other elements that are frequently deficient in soils. The various elements in the ash were calculated as oxides, with average percentages as follows: Phosphoric acid, 2.68; calcium oxide, 10.41; potassium oxide, 45.15; and magnesium oxide, 4.76; a total of 63.00% of important fertilizing constituents.

Although soils in western Oklahoma do not usually respond to applications of phosphate, potash, or lime, fertilization with small quantities of cotton burs may be beneficial on many farms because the nitrogen and organic matter in most cultivated soils are rapidly disappearing as a result of tillage, cropping, and erosion. Farmers who haul snapped cotton to a gin and fail to return the burs are losing approximately 21 pounds of nitrogen for each ton of burs removed from their land. This amount of nitrogen is greater than the nitrogen occurring in one-half bale of seed cotton.

SUMMARY

The effect of applying cotton burs and their ashes to Kirkland soil on the yield of seed cotton has been studied at Oklahoma Agricultural Experiment Station since 1926. Three tons of burs applied at intervals of 3 years, either plowed or disked into the soil, give as good returns as 6 tons on adjacent plats treated in a similar manner. The average increase was 189 pounds per acre when the lightest application was plowed under and 166 pounds when disked into the soil. The highest average gain from the heaviest treatment was 170 pounds of seed cotton per acre. Ashes from equivalent amounts of burs only produced about one-half as great an increase in yield as the burs.

Cotton burs were collected from 22 counties in Oklahoma and analyzed for their fertilizing constituents. These samples contained an average of 8.73% ash, 1.04% nitrogen, 0.10% phosphorus, 0.65% calcium, 3.39% potassium, and 0.25% magnesium, calculated on a moisture-free basis. The nutrient content of cotton bur ashes was calculated, and the average quantity of different oxides was found to be as follows: Phosphoric acid (P_2O_5), 2.68%; calcium oxide, 10.41%; potassium oxide, 45.15%; and magnesium oxide, 4.76%.

LITERATURE CITED

1. DANIEL, HARLEY A., and HARPER, HORACE J. The relation between total calcium and phosphorus in mature prairie grass and available plant food in the soil. Jour. Amer. Soc. Agron., 26:986–992. 1934.

2. ————, ————. The relation between effective rainfall and total calcium and phosphorus in alfalfa and prairie hay. Jour. Amer. Soc. Agron., 27:644–652. 1935.
3. DEAN, L. A., and TRUOG, E. Determination of manganese and magnesium in soils and silicate rocks. Ind. and Eng. Chem., 7:383–385. 1935.
4. DOWELL, C. T., and FRIEDEMANN. The economic uses to which bolly refuse may be placed and the composition of bolly cotton seed and their products. Okla. Agr. Exp. Sta. Bul. 121. 1918.
5. FLY, CLAUDE, HARPER, HORACE J. and SMITH, OTTO M. Commercial utilization of waste from cotton gins. The Cotton Oil Press, Memphis, Tenn., September, 1929.
6. FRAPS, G. S. The chemical composition of the cotton plant, Tex. Agr. Exp. Sta. Bul. 247. 1919.
7. HARPER, HORACE J. Easily soluble phosphorus in Oklahoma soils, Okla. Agr. Exp. Sta. Bul. 205. 1932.
8. McHARGUE, J. S. Mineral constituents of the cotton plant. Jour. Amer. Soc. Agron., 18:1076–1083. 1926.
9. McBRYDE, J. BOLTON. A chemical study of the cotton plant. Tenn. Agr. Exp. Sta. Bul., 4: No. 5. 1891.
10. MURPHY, H. F. The nitrogen, phosphorus, and calcium content of the cotton plant at pre-blooming to early boll stage of growth. Jour. Amer. Soc. Agron., 28:52–57. 1936.
11. TRUOG, E., VOLK, G. W., PING, and VOLK, N. J. The determination of potash by the sodium cobaltinitrite method. Unpublished data, Univ. of Wis. 1937.
12. VIEHAEUER, ARNA, CHERNOFF, LEWIS H., and JOHNS, CARL O. Chemistry of the cotton plant with special reference to upland cotton. Jour. Agr. Res., 13:345–352. 1918.
13. WHITE, H. C. The feeding of cotton. Ga. Agr. Exp. Sta. Bul. 114. 1915.

EFFECT OF CERTAIN CROPS AND SOIL TREATMENTS ON SOIL AGGREGATION AND THE DISTRIBUTION OF ORGANIC CARBON IN RELATION TO AGGREGATE SIZE[1]

W. H. METZGER AND J. C. HIDE[2]

CROPS differ with respect to their influence on the physical properties of the soil. Certain crops appear to leave the soil upon their removal in a mellow or friable condition, while others apparently exert little effect and still others cause the soil to become "hard." Most of this knowledge is based on purely qualitative observations in the field, though quantitative measures in the form of plow draft tests, ease of penetration tests, and, more recently, aggregate analyses, have been used. Until recent years no methods were available by which the degree of aggregation of soils could be satisfactorily measured. Several methods have now been proposed which offer promise of yielding very valuable results. Among these may be mentioned the elutriation method proposed by Baver and Rhoades (3),[3] the wet sieve method described by Yoder (11), the sedimentation tube method of Cole and Edlefsen (6), and methods involving the use of the hydrometer reported by Bouyoucos (5) and Gerdel (8).

On purely theoretical grounds the writers believe that the sedimentation tube method of Cole and Edlefsen should be the most desirable type of procedure in aggregate analysis because in this method mechanical abrasion is reduced to a practical minimum. The objections based on particle density, particle shape, and particle size raised by Yoder against the elutriation method, however, apply to the Cole and Edlefsen procedure as well. These objections, the writers believe, are more than offset by the reduction in mechanical abrasion of the sedimentation tube method as compared to the wet sieve procedure.

The Cole and Edlefsen soil tube was used in the work reported here. The procedure recommended by them was found to be satisfactory and with strict adherence to its details reproducible results could be obtained. Appreciable variations in time of slaking the soil, method of mixing the sample, or draining the tube always resulted in measurable variations in the data.

EFFECT OF SOME CROPS AND SOIL TREATMENTS ON SOIL AGGREGATION

FIELD STUDIES

Samples taken from field plats supporting various crops were studied and a few samples from an experiment involving periods of fallow of various lengths were utilized. A majority of the samples

[1]Contribution No. 282 from the Agronomy Department of the Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication July 5, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 842.

involved in the comparison of the effects of various crops were taken from adjacent long, narrow plats, 13½ feet by 161⅓ feet. Plats of such shape are desirable in this type of study since inherent differences in soil morphology are encountered if the samples for comparison are not drawn within comparatively narrow limits. Inherent differences in aggregation are oftimes greater than those produced by different vegetative cover. Some of the samples used in this study, however, were taken from adjacent 1/10 acre plats, 27 feet by 161⅓ feet.

The samples were removed from the plats with a spade and care was exercised to take that portion of the soil removed at each spadeful which was apparently not compacted in the removal. Six such samples, taken to a depth of 6 inches, were mixed together on a piece of canvas and a composite sample removed for analysis. This composite sample was carefully screened through a wire screen with ½-inch mesh, mixed thoroughly and a quantity sufficient to supply approximately 54 grams of oven-dry soil was removed for analysis.

The results of the analyses of the field samples are listed in Table 1. The samples are grouped in the manner in which comparisons should be made.

It will be noted from the data in Table 1 that duplicate comparisons were obtained in most cases. In general these show very good agreement. In Fig. 1 the data from one pair of plats in each of the following comparisons are shown graphically; corn and kafir, oats after corn and oats after kafir, 1 year of fallow and 2 years of fallow.

The slaked and mixed soil in the tube was allowed a 30 seconds sedimentation period, with the tube in a vertical position. After this period the tube was turned to an exactly horizontal position and the suspended soil allowed to settle on the segments of the inner tube. In Table 1 and Fig. 1 are shown only the summation percentages for the top 10 segments, referring to the tube in a vertical position. The lower five segments are disregarded because of the influence of the increased viscosity, or the "piling-up" effect, resulting from the concentration of soil particles at these lower depths during the sedimentation period. It should be borne in mind in interpreting the data of the table or graph that the more aggregated the soil the lower are the summation percentages for the upper 10 segments, and *vice versa*.

There are several points of interest in these data. It is commonly believed that a sorghum crop, for some reason possibly never adequately explained, produces an unfavorable after-effect upon the physical condition of the soil. These data indicate that at the time the crops matured there was practically no difference in the aggregation of the soil under corn and that under sorghum. Later, however, when the same plats were sampled under oats stubble, there was a distinctly greater degree of aggregation in the soil of the plat whose previous crop had been corn than in the one where sorghum preceded the oats. This occurrence makes it appear that the unfavorable after-effect of sorghums on the physical condition of the soil, if any, originates during the decomposition of the sorghum residues. On these plats all of the corn and kafir stover as well as the stubble and roots are returned to the land. Therefore if a dispersing action is created

TABLE 1.—*Aggregation of soil as affected by various crops under field conditions.*

Crop	Percentage of the total sample having particles with mean settling velocities equal to or less than the indicated amount in centimeters per second									
	0.085	0.254	0.423	0.592	0.762	0.931	1.100	1.270	1.439	1.608
Corn (a)*	3.40	6.80	10.44	14.36	18.44	22.75	27.35	32.16	37.14	42.46
Kafir (a)	3.39	6.88	10.74	14.64	18.78	23.09	27.81	32.71	37.79	43.02
Corn (b)	2.96	6.13	9.65	13.36	17.31	21.55	26.09	30.85	35.83	40.93
Kafir (b)	2.87	5.92	9.28	12.95	16.84	20.97	25.37	30.00	34.76	39.77
Oats after corn (a)	2.72	6.31	9.86	13.65	17.66	21.89	26.27	30.77	35.53	40.31
Oats after kafir (a)	4.12	8.34	12.69	17.24	22.00	27.03	32.10	37.25	42.46	47.91
Oats after corn (b)	3.72	7.73	11.88	16.33	20.78	25.58	30.71	35.95	41.23	46.77
Oats after kafir (b)	4.69	9.38	14.36	19.41	24.63	30.00	35.51	41.09	46.75	52.53
2 yrs. alfalfa (a)	3.72	7.15	10.92	14.92	19.09	23.50	28.05	32.88	37.87	42.97
2 yrs. sweet clover (a)	3.71	7.48	11.39	15.52	19.75	24.31	29.16	34.19	39.31	43.70
2 yrs. alfalfa (b)	3.03	6.17	9.55	13.14	16.93	21.12	25.59	30.34	35.26	40.35
2 yrs. sweet clover (b)	2.92	6.22	9.71	13.39	17.21	21.35	25.76	30.32	35.05	39.91
Soybeans (a)	4.17	8.28	12.73	17.38	22.21	27.28	32.56	38.16	43.69	49.51
1 yr. sweet clover (a)	3.35	6.81	10.60	14.65	18.92	23.35	28.08	33.06	38.29	43.68
Soybeans (b)	3.74	7.55	11.67	15.95	20.43	25.25	30.39	35.53	40.79	46.17
1 yr. sweet clover (b)	3.48	7.02	10.92	15.00	19.30	23.77	28.53	33.46	38.51	43.73
Fallow 1 yr., alfalfa 2 yrs.	1.21	2.21	3.28	4.48	5.80	7.22	8.80	10.52	12.36	14.36
Fallow 2 yrs., alfalfa 1 yr.	1.51	2.99	4.67	6.42	8.44	10.61	12.87	15.30	17.83	20.65
Fallow 1 yr., soybeans 2 yrs.	1.80	3.58	5.50	7.56	9.85	12.55	15.50	18.27	21.65	25.04
Fallow 2 yrs., soybeans 1 yr.	2.40	4.47	7.45	10.20	13.30	16.67	20.38	23.75	27.88	32.10
Fallow 1 yr., corn 2 yrs.	1.85	3.42	5.12	7.15	9.12	11.43	13.78	16.32	18.95	21.87
Fallow 2 yrs., corn 1 yr.	2.12	4.09	6.34	8.82	11.41	14.40	17.56	20.86	24.58	28.33

*Letters indicate duplicated treatment.

when the sorghum residues undergo decomposition such dispersion should be at its maximum under the conditions existing in this experiment. Breazeale (4) noted that the dispersing action occurred after the sorghum crop was removed and during the decay of its residues. His explanation of the cause is probably not valid for acid soils. Ayyar, Kasinath, and Balakrishnan (2) suggest that an increase in the active sodium of the soil following sorghum cropping may be a cause.

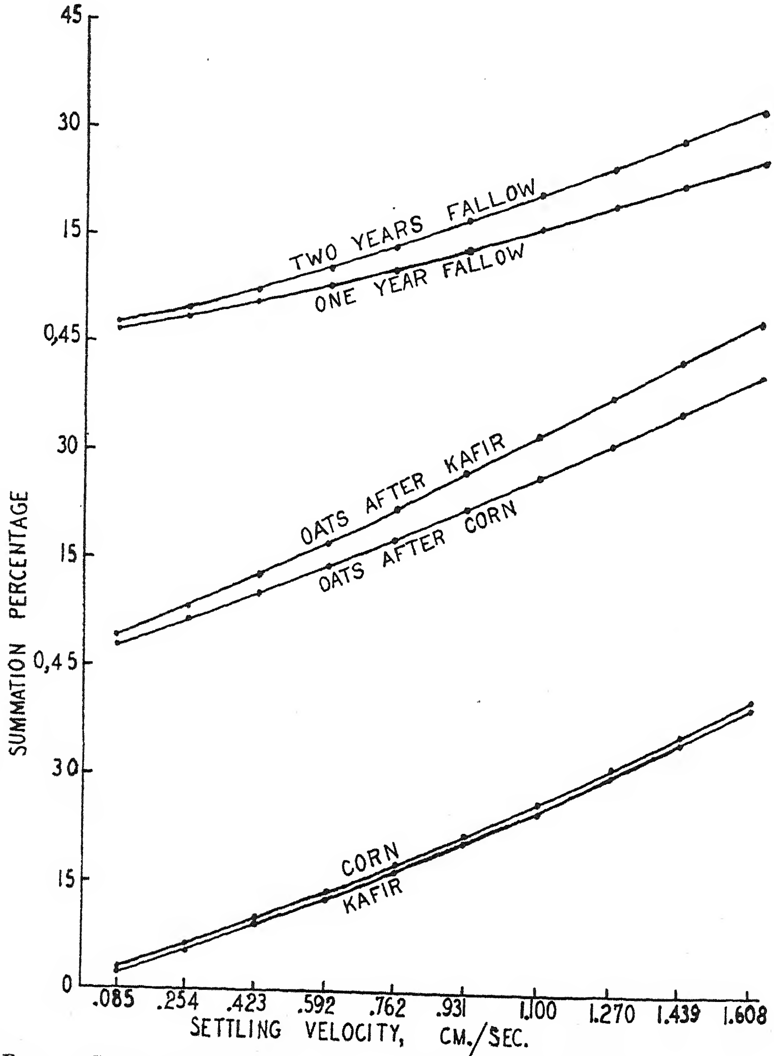

FIG. 1.—Curves showing the summation percentages of aggregates with settling velocities equal to, or less than, the indicated values, for three paired experiments.

A second point of interest is the similarity of the values for alfalfa and sweet clover. The latter, however, left the soil appreciably better aggregated after one summer's growth than did soybeans. A third point of interest is the difference in the degree of aggregation between soil fallowed for 1 year and cropped for 2 years, on the one hand, and soil fallowed for 2 years and cropped for 1 year on the other. Soil fallowed 2 years or more under the rainfall conditions existing at this station loses by leaching soluble salts produced in the surface soil and undergoes some eluviation. In such soil a thin, compact zone or layer develops a few inches below the surface. The effect is indicated in the aggregate analysis data for the plats fallowed for 2 years. The soil on which the fallow experiment is located is distinctly different from that on which the crops listed in the first part of the table were grown. The fallow soil, which has not been correlated recently, would probably be classified as a deep phase Derby silt loam. It is better aggregated than the Derby silt loam represented in the first part of the table.

GREENHOUSE STUDIES

It was desired to study the effect of several crops and of the use of lime upon soil uniformly prepared and cropped under controlled conditions in the greenhouse. Soil from an area in the fallow experiment mentioned above which had been fallowed for 3 years and which had developed a compact zone was used for the greenhouse study. The dispersing effect which it had undergone, it was believed, would make it a desirable soil for this experiment. It had a high organic matter content, however, and subsequent results made it appear that it was not a particularly good choice. The pH value of the soil was 5.7 and precipitated $CaCO_3$ was applied to certain jars at the rate of 2 tons per acre on a weight basis, the lime being mixed with the entire mass of soil.

The soil was removed with a shovel and brought to the greenhouse where it was screened through a ½-inch screen. It was then thoroughly mixed and weighed quantities placed in 2-gallon stone jars. The soil was treated or cropped as noted in the following table. Triplicate jars for each treatment or crop were provided. When the shortest season crops began to approach maturity the process of taking down the jars was started as rapidly as the samples could be analyzed. One jar of each crop or treatment was taken down. When one of each of the triplicates had been analyzed a second series was likewise removed and finally the third. The average length of time each treatment or crop reacted upon the soil is therefore comparable to all others. When each jar was taken down the plants were removed, the soil put through a ½-inch screen, thoroughly mixed, and a portion removed for analysis. Good agreement between triplicates was obtained when strict adherence to procedures was practiced. The results obtained from the triplicate determinations in each case were averaged and the averages are shown in Table 2.

Some of the results obtained from this experiment were rather surprising. For example, the soil kept bare in the greenhouse (listed as fallow in the table) and in which was maintained a moisture con-

TABLE 2.—*Soil aggregation as affected by various crops under greenhouse conditions.*

Soil treatment or crop	Percentage of the total sample having mean settling velocities equal to or less than the indicated amount, in centimeters per second									
	0.085	0.254	0.423	0.592	0.762	0.931	1.100	1.270	1.439	1.680
Original soil	1.59	3.27	5.04	7.05	9.31	11.80	14.48	17.35	20.39	23.51
Fallow, not limed	1.28	2.60	4.04	5.60	7.41	9.28	11.31	13.81	15.78	18.29
Fallow, limed	1.31	2.63	4.09	5.67	7.49	9.40	11.43	13.61	15.92	18.34
Sweet clover, not limed	1.79	3.53	5.41	7.43	9.11	11.98	14.52	17.14	19.87	22.76
Sweet clover, limed	1.26	2.45	3.83	5.35	7.06	8.89	10.85	12.93	15.13	17.49
Red clover, not limed	1.81	3.60	5.55	7.68	9.99	12.53	15.12	28.03	21.01	24.28
Red clover, limed	1.46	2.97	4.60	6.40	8.45	10.68	13.13	15.75	18.54	21.48
Bluestem*	2.14	4.17	5.71	8.74	11.27	14.03	16.92	20.00	23.17	26.54
Bluegrass†	2.00	4.06	6.28	8.56	11.05	13.66	16.53	19.47	22.52	25.72
Buffalo grass‡	1.78	3.66	5.71	7.98	10.42	13.12	15.98	19.18	22.29	25.71
Wheat	1.63	3.27	4.76	7.05	9.22	11.61	14.18	16.97	19.87	22.96
Corn	1.87	3.60	5.42	7.41	9.62	12.14	14.50	17.22	20.06	23.03
Kafir	1.61	3.06	4.65	6.35	8.27	10.32	12.57	14.96	17.54	20.22
Soybeans	1.43	2.78	4.37	6.08	8.07	10.28	12.49	15.01	17.68	20.91

**Andropogon scoparius.*
†*Poa pratensis.*
‡*Buchloe dactyloides.*

dition similar to that of fallow in the field, showed a greater degree of aggregation than the original soil or the soil of any except one of the cropped jars. The limed and unlimed fallow soil showed almost identical results. The reason for the behavior of the uncropped soil is somewhat obscure. However, as explained before, the soil was high in its content of organic matter. The jars were not provided with drains and the temperature and moisture conditions were very favorable for biological activity. Hence any soluble salts released accumulated in the soil. Furthermore, downward movement of water was restricted. These facts may account for the high degree of aggregation of this soil. Conrad (7) has shown a relationship between nitrate accumulation and flocculation of soil colloids.

Grasses had surprisingly little effect on aggregation. The three types used produced very similar values and the soil from beneath the grasses was less aggregated than that from beneath any other crop or treatment. The bluestem grass and the buffalo grass, which were transplanted from the field, did not do particularly well in the greenhouse. The bluegrass, however, also transplanted, grew luxuriantly. It is probable the growth period was too short for the plants to exert a beneficial effect upon the physical condition of the soil. It may be, however, that grasses, after all, are not particularly effective in promoting soil aggregation, at least not over a short period of time.

Wheat and corn were indicated to have influenced the soil in a very similar manner. The soil under kafir was better aggregated than that under corn, while soybeans produced values similar to those for the sorghum crop.

Red clover and sweet clover in unlimed soil gave results similar to those for corn and wheat. When the soil was limed, however, and these crops grown, the degree of aggregation was appreciably increased despite the fact that there was no noticeable response of the plants to lime on this soil.

There have been some differences of opinion among soil scientists regarding the relationship of lime, or more specifically, calcium, to soil aggregation. It has long been believed that the use of lime on lime-deficient soils under field conditions promoted granulation in such soils. Very few data were ever presented to prove that such a process actually occurred. On the other hand, laboratory studies have indicated that H^+ saturated soils were as well or better aggregated than soils saturated with Ca^{++}. The results of the study presented in this paper may assist in harmonizing these views. It may be that the field observations and the laboratory results are both logical, but that it requires the combined action, or interaction, of lime and plant to produce improved soil aggregation. The problem requires further study.

DISTRIBUTION OF ORGANIC CARBON IN RELATION TO AGGREGATE SIZE

Numerous workers have reported results indicating an important rôle of organic matter in soil aggregation. Among recent papers may be mentioned those of Sideri (10) and Myers (9). While making the aggregate analyses reported in this paper, it was observed that the

least aggregated soil fractions were lighter in color than the better aggregated soil. It was believed the lighter color was attributable to a lower content of organic matter. Accordingly, samples were collected for organic carbon determinations. Samples from two segments from near that end of the tube which was uppermost during the sedimentation period were selected to represent the least aggregated soil. These segments were designated Nos. 3 and 4. Segment No. 1 at the top was not used since light, undecomposed organic matter always floated to the surface and contaminated the sample on this segment. Segment No. 2 was tried, but it appeared that some such contamination occurred there also. Samples from segments 8, 9, and 10 were utilized to represent slightly better aggregated soil and samples from the lowest segments, 12, 13, 14 and 15, were used to represent soil best aggregated. Such studies were made with from 6 to 8 field soil samples and 12 to 13 samples from the greenhouse experiment. Since the results are very similar only the data from the field samples are presented. Organic carbon was determined by the Schollenberger method as outlined by Allison (1). The results are listed in Table 3.

TABLE 3.—*Organic carbon of differently aggregated portions of the soil.*

Field experiment sample description	Percentage of organic carbon in the soil on tube sections indicated									
	Top			Middle			Bottom			
	2	3	4	8	9	10	12	13	14	15
Kafir (a)*	1.59	1.35	1.45	1.38	1.51	1.39	1.54	1.60	1.65	—
Corn (a)	1.45	1.34	1.29	1.47	1.58	1.46	1.51	1.58	1.66	—
Kafir (b)	—	1.62	1.59	1.66	1.63	1.69	—	1.73	1.89	1.82
Corn (b)	—	1.64	1.68	1.71	1.74	1.73	—	1.82	1.85	1.87
Oats after kafir (a)	—	1.46	1.56	1.62	1.52	1.64	—	1.74	1.80	1.84
Oats after corn (a)	—	1.56	1.51	1.55	1.55	1.56	—	1.65	1.73	1.74
Oats after kafir (b)	—	1.32	1.32	1.40	1.32	1.41	—	1.47	1.32	1.43
Oats after corn (b)	—	1.37	1.41	1.47	1.44	1.47	—	1.45	1.47	1.51

*Letters in parentheses indicate duplicated treatments.

The data indicate differences in organic carbon content which are rather consistent. In order, however, to obtain a better measure of the importance of the differences, comparisons were made by Student's method (Love's tables) of pairs of aggregate groups from the data for the field samples and also for the greenhouse samples. The comparisons and the odds supporting the differences are shown in Table 4.

The differences of organic carbon content between the less aggregated portions of the soil and the more aggregated portions are significant. Out of 16 mean differences obtained from paired groups made up of from 6 to 13 comparisons, 14 are supported by significant odds. No explanation can be offered for the result of the last comparison listed in the table which shows a negative mean difference, that is, the aggregates on segment 9 showed slightly more organic carbon on the average than those on segment 15. This result is at variance with that obtained from the field data.

TABLE 4.—*Comparison of organic carbon of soil samples from various segments of the soil tube and odds for significance of the differences.*

Comparison, tube segments	Mean difference, %	Standard deviation	Z value	n	Odds
		Field Experiment			
3 with 8	.075	.055	1.36	8	225 to 1
3 with 9	.080	.081	0.99	8	56 to 1
4 with 9	.060	.098	0.61	8	12 to 1
3 with 13	.170	.077	2.19	8	3100 to 1
4 with 14	.195	.120	1.62	8	550 to 1
4 with 15	.190	.072	2.64	6	985 to 1
9 with 13	.090	.071	1.27	8	164 to 1
10 with 14	.130	.116	1.12	8	94 to 1
10 with 15	.120	.073	1.63	6	132 to 1
9 with 15	.170	.088	1.93	6	258 to 1
		Greenhouse Experiment			
3 with 9	.297	.122	2.43	12	>10,000 to 1
4 with 10	.170	.152	1.12	12	550 to 1
3 with 14	.370	.366	1.01	12	310 to 1
4 with 15	.210	.174	1.21	12	950 to 1
8 with 14	.135	.125	1.08	13	725 to 1
9 with 15	−.03	.171	−.175	13	0 to 1

ULTIMATE MECHANICAL COMPOSITION OF SOME OF THE AGGREGATE SEPARATES

The presence of more organic carbon in the more aggregated portions of the soil as demonstrated by these data lends weight to the assignment of an important rôle to organic matter in the process of soil aggregation. It seems possible, too, that the differences in carbon content may represent the more active portion of the organic matter and probably that portion which is most effective in the binding of the mineral particles into aggregates.

It was considered possible that the differences in organic matter content of the various aggregate groups might not be particularly significant if ultimate particle size also differed appreciably in these groups. Since the quantities of soil recoverable from the upper segments of the tube were small, numerous samples from various segments were composited, thoroughly mixed, and a mechanical analysis made. Organic matter was not removed, but the soil was dispersed and the determinations were made by the Bouyoucos hydrometer method. The distribution of ultimate particles as thus determined is indicated in Table 5.

The results listed in Table 5 indicate little or no tendency toward ultimate particle separation in the aggregate analysis method used. The slightly higher value for total sands in segments 1 to 5 may be accounted for, at least in part, by the undecomposed organic matter in these segments which, in the mechanical analysis floated to the surface of the suspension and consequently did not affect the hydrometer. It is believed, therefore, that the aggregate analysis data presented offer a true picture of the degree of aggregation of the soil.

TABLE 5.—*Ultimate particle distribution in the aggregate separates.*

Tube segments	Total sands %	Silt %	Clay %
1–5 (upper)	24	54	22
6–9 (middle)	20	56	24
10–12 (lower middle)	19	60	21
13	23	56	21
14	21	56	23
15	21	54	25

Also the distribution of organic carbon among the various separates takes on added significance when it is revealed that ultimate particle size in these aggregates is similar.

SUMMARY

Studies of the effect of several crops and certain soil treatments on the degree of aggregation of soils in the field and in the greenhouse are presented. The organic carbon contents of various size groups of soil aggregates obtained from a single soil sample were determined.

Samples taken from the soil under growing corn and kafir in field and greenhouse showed as good aggregation under the sorghum crop as under corn. When oats succeeded these two crops in the field, however, soil samples removed from the oats stubble revealed a greater degree of dispersion where oats followed sorghum than where corn was the preceding crop. Sweet clover left the soil better aggregated after 1 year's growth than soybeans, while alfalfa and sweet clover gave similar results. Soil fallowed for 2 years in the field was less aggregated than soil fallowed for 1 year.

Limed soil supporting sweet clover and red clover in a greenhouse experiment was more highly aggregated than similar soil unlimed but supporting these crops. Unlimed and unleached fallow soil in the greenhouse was as well aggregated as limed fallow soil. It is suggested that perhaps the combined action of lime and a legume crop, or possibly other crops, produces an aggregating force which lime alone may not exert. The grasses failed to produce the aggregation of the soil expected of them, but their failure in this experiment may have been due to the shortness of the growth period.

The more aggregated portions of the soil contained significantly more organic carbon than the less aggregated portions. Ultimate particle size in the various size groups of aggregates was quite similar. Hence it is believed these results lend weight to the assignment of an important rôle to organic matter in the aggregation of the mineral particles of soils.

LITERATURE CITED

1. ALLISON, L. E. Organic soil carbon by reduction of chromic acid. Soil Science, 40:311–320. 1935.
2. AYYAR, V. RAMANATHA, KASINATH, S., and BALAKRISHNAN, M. R. Injurious after-effects of sorghum growing. Cur. Sci. (India), 4:9. 1935. (Abstract in Exp. Sta. Rec., 74:482. 1936. Original not seen.)

3. BAVER, L. D., and RHOADES, H. F. Aggregate analysis as an aid in the study of soil structure relationships. Jour. Amer. Soc. Agron., 24:920–930. 1932.
4. BREAZEALE, J. F. The injurious after-effects of sorghum. Jour. Amer. Soc. Agron., 16:689–700. 1924.
5. BOUYOUCOS, G. J. A method for making mechanical analysis of the ultimate natural structure of soils. Soil Science, 40:481–485. 1935.
6. COLE, R. C., and EDLEFSEN, N. E. A sedimentation tube for analyzing water-stable soil aggregates. Soil Science, 40:473–479. 1935.
7. CONRAD, J. P. The relation of colloid dispersion in soils to chemical changes induced by biological transformations of organic materials. Soil Science, 37:179–201. 1934.
8. GERDEL, R. W. Adaptation of the hydrometer method to aggregate analysis of soils. Jour. Amer. Soc. Agron., 30:107–110. 1938.
9. MYERS, H. E. Physiochemical reactions between organic and inorganic soil colloids as related to aggregate formation. Soil Science, 44:331–359. 1937.
10. SIDERI, D. I. On the formation of structure in soil: II. Synthesis of aggregates; on the bonds uniting clay with sand and clay with humus. Soil Science, 43:461–482. 1937.
11. YODER, R. E. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Jour. Amer. Soc. Agron., 28:337–351. 1936.

INFLUENCE OF ARSENICAL TREATMENTS UPON RAPID TESTS FOR SOIL PHOSPHORUS[1]

M. S. ANDERSON AND J. W. BENGTSON[2]

RAPID chemical tests for water-soluble or for available phosphates in soils ordinarily employ the Deniges reaction. The cerulean blue color is produced either by phosphorus or by arsenic. An improved method for determination of either of these elements was described by Truog and Meyer (5)[3] in 1929. When arsenic is distilled over in the form of arsenic tribromide previous to developing the color reaction, phosphorus is of course eliminated as a factor in the test. But, in the rapid soil tests, arsenic as well as phosphorus is dissolved by the reagents, though it is generally assumed that the quantity of arsenic contributing to the color is negligible.

This general assumption is far from the truth in some sections of the country. Arsenic compounds, particularly arsenates of lead and calcium, are widely used in agricultural practices for the control of insects affecting cotton, orchards, and truck crops. After these materials have been used for several years for spraying such crops, considerable arsenic may accumulate in the soil (1).

In the area of Japanese beetle infestation, arsenate of lead is widely used to destroy the insect in its larval stage. The usual rates of application for this purpose are from 200 to 500 pounds of arsenate of lead to the acre. Frequently much higher rates are used, and it is usually necessary to repeat applications every few years. Similar applications of arsenate of lead are frequently used in the control of the larvae of the May beetle or June bug, earthworms, and other pests.

In recent years there has been a decided increase in the use of rapid tests for the determination of the fertilizer requirements of lawns, parks, golf courses, and similar turfed areas. On several occasions it has been observed that the rapid methods used for the testing of soil samples taken from such areas indicated a higher phosphoric acid content than appeared reasonable, judging from fertilizer practice. Since arsenate of lead is so extensively used in such turfed areas it was suspected as a possible source of error. Apparently, no results have been published on the use of rapid phosphorus tests on soils which have received arsenical treatment.

In connection with some experimental work where plats received varying amounts of arsenicals and phosphoric acid it was noted that there was a great irregularity in the available phosphoric acid content of the soil as indicated by one of the rapid chemical tests. Check plat soils showed little or no available phosphate by this test, while soils receiving either arsenical or phosphate treatments showed the presence of an adequate phosphate supply. In these particular plats rela-

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[1]Joint contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture and the Greens Section, U. S. Golf Association. Received for publication July 5, 1938.

[2]Senior Chemist, Bureau of Chemistry and Soils, and Agronomist, Greens Section, U. S. Golf Association, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 846.

TABLE 1.—*Available phosphorus indicated in soils variously treated with fertilizers and arsenicals.*

Lab. No.	Plat No.	Treatment, pounds per 1,000 sq. ft.		Indiana method	Morgan method	Truog method, lbs. per acre
		Total amount added	Applications			
C-3767	8	Check		Very low	Low	12
C-3770	11	1.5 lbs. P_2O_5	3 times, grade 6-3-2, 1936-37	Very low	Low	32
C-3768	9	12 lbs. P_2O_5	3 times, grade 6-24-2, 1936-37	Medium	Medium	168
C-3766	7	5 lbs. arsenic acid	6 times, 1936-37	Low	Medium	80
C-3769	10	5 lbs. arsenic acid 1.5 lbs. P_2O_5	6 times, 1936-37 3 times, grade 6-3-2, 1936-37	Medium	Medium	48
C-3765	6	5 lbs. arsenic acid 12 lbs. P_2O_5	4 times, 1936-37 3 times, grade 6-24-2, 1936-37	High	High	132
C-3761	2	12 lbs. arsenic acid	4 times, 1935-36	Medium	High	80
C-3762	3	12 lbs. arsenic acid	4 times, 1935-36	Medium	High	88
C-3772	13	12 lbs. arsenic acid 3.0 lbs. P_2O_5	6 times, 1934-37 2 times, grade 6-12-4, 1934-35	High	Very high	240
C-3760	1	24 lbs. arsenic acid	3 times, 1935-36	High	High	104
C-3763	4	40 lbs. lead arsenate	4 times, 1933	Very high	Medium	108
C-3764	5	40 lbs. lead arsenate	1 time, 1936	Very high	Low	104
C-3771	12	9 lbs. As_2O_5 3 lbs. P_2O_5	6 times, 1934-37 2 times, grade 6-12-4, 1934-35	High	Very high	264

tively large quantities of arsenic had been applied. However, repeated treatments such as used in field practice would ultimately effect a total accumulation of arsenic comparable to the rates used in these tests.

Further samples were taken from these plats and tested in the laboratory by three of the widely used rapid phosphorus tests developed at different state experiment stations.

The soil extracting solutions employed in these several methods differ widely. The Indiana procedure (3) calls for essentially a 0.1 N hydrochloric acid solution (approximately pH 1.0); the Morgan method (2) prescribes a relatively strong sodium acetate solution with acetic acid added to give it a pH of about 4.8. The Truog extracting solution (4) consists of 0.002 N sulfuric acid buffered with ammonium sulfate at pH 3.0. Ratios of soil and solution also differ in these tests. The results are given in Table 1.

It is evident from Table 1 that the relative quantities of phosphorus or arsenic, or both, dissolved by the different extracting solutions vary somewhat but show the same general trends. It is clear, also, that rapid tests for phosphorus, as ordinarily conducted, are meaningless when soils have received any kind of arsenical treatments. Longer procedures involving a separation of phosphorus and arsenic are essential for furnishing an idea of the phosphorus situation when arsenic has been added.

LITERATURE CITED

1. Cooper, H. P., *et al.* Effect of calcium arsenate on the productivity of certain soil types. S. C. Exp. Sta. 44th Ann. Rpt.: 28–36. 1931.
2. Morgan, M. F. The universal testing system. Conn. Agr. Exp. Sta. Bul. 392. 1937.
3. Thornton, S. F., Connor, S. D., and Fraser, R. R. The use of rapid chemical tests on soils and plants as aids in determining fertilizer needs. Purdue Univ. Agr. Exp. Sta. Circ. 204. 1934.
4. Truog, Emil. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–82, 1930.
5. ———— and Meyer, A. H. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Ind. and Eng. Chem., Anal. Ed., 1:136–139. 1929.

RELATIONSHIPS BETWEEN SOME SOIL MEASUREMENTS AND THE INCIDENCE OF THE TWO COMMON POAS[1]

H. B. HARTWIG[2]

OUR knowledge of bluegrass ecology is based largely on observations and opinions and only to a slight degree on the results of measurements. It is of course conceded that studied observations of agronomists of training and experience deserve respect until careful experimental work proves them to be inaccurate. This investigation, employing soil analytical methods which are known to have their limitations, is intended only as a step toward replacing crop ecological opinion with something tangible.

Within the humid northeastern portion of the United States, where the dominant pasture grasses are believed to be quite generally Poas, are found areas in which each of the two common species of that genus dominates. An interesting but much involved question is, "Why does *Poa compressa* (Canada bluegrass) dominate in the lake counties of western New York on some of the most agriculturally important soils of the state; while *Poa pratensis* (Kentucky bluegrass) dominates in the Ithaca area on soils not so highly regarded agriculturally?" Popular agronomic opinion would predict the reverse of this.

Most bluegrass pastures in New York are mixed. That is, patches of either species of Poa may be found in pastures where the other dominates. Do such patches reflect soil differences or are they the result of chance? Data contributing to the answers to these questions should be helpful in eventually formulating a sound bluegrass ecology.

REVIEW OF LITERATURE

Results of plat experiments dealing with the difference in fertility levels at which the two common Poas thrive are rare. Numerous ecologists have attempted to correlate the incidence of plants in nature with hydrogen-ion concentration or with presence or absence of calcium carbonate. Salisbury (19)[3] believed that reaction preference was significantly shown if an occurrence frequency curve displayed a distinct mode. The work of Olsen (17) indicated that factors other than acidity influenced the occurrence of *Poa pratensis* in Danish meadows.

Cooper (2) collected 1868 samples of soil from beneath swards in 546 New York pastures; determined pH potentiometrically, and presented frequency distribution tables for various grasses in 10 pH ranges. Cooper's range for *Poa pratensis* is distinctly broader than Olsen's. Cooper suggested that a well-balanced supply of available cationic and anionic nutrient materials with relatively high oxidation-reduction potentials is much more effective than the hydrogen-ion

[1]A review of a thesis submitted to the Graduate School of Pennsylvania State College in June 1937 in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication July 6, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 860.

concentration of the soil in determining the dominance of various pasture plants.

Steiger (21) observed the effect of physiographic position on the occurrence of Poas in prairie swards. Cooper, Wilson, and Barron (3) expressed belief that various pasture plants tolerate different nutritional complexes. Dix (6) failed to correlate vegetation with certain chemical and physical measurements in 53 old Holstein-Schleswig pastures. Skinner and Noll (20) brought about a change in Poa species dominance under plat conditions, *Poa pratensis* being favored by applications of fertilizer.

Agronomists, too numerous to mention, have expressed the belief, unsupported by experimental evidence, that *Poa pratensis* requires a higher fertility level than *Poa compressa*. Some have been of the opinion that the latter grass is more likely to dominate on acid thin, dry soils of heavy texture.

Analyses made by numerous investigators of the herbage collected from areas where plants may have had opportunity to reflect equilibrium with environment seem to be in agreement on only two points, *viz.*, that *Poa pratensis* is higher in nitrogen (or protein) than *Poa compressa*, and likewise higher in phosphorus.

Scores of investigators have given attention to various phases of cation exchange. Many have concerned themselves with methods of determination. Several have studied the effect of cropping and fertilizing on the exchangeable bases of the soil. However, the investigators who have attempted to correlate replaceable cations with crop response are very few.

The work of Hoagland and Martin (9) and that of Gedroiz (8) make it apparent that exchangeable bases are not the only ones available to plants. The former writers also call attention to the possibility of luxury consumption of nutrients by plants. On the other hand, Fraps (7), Wheeting (22), and Bauer and Snider (1) have found fairly good agreement between replaceable potassium and plant response.

Kelley (11) has pointed out the limitations of cation exchange. From the literature it appears that the measurement of a replaceable base at any one time is not necessarily a measure of the ability of the soil to supply that base, but reflects the net effect of supply together with crop removal.

THE AREAS STUDIED

Typical provinces (or areas) were chosen on two fairly well-known soil types. *Poa pratensis* dominated the vegetation in every pasture examined on the Dunkirk silty clay loam. *Poa compressa* dominated in every day[4] pasture visited on the Ontario loam. The *Poa pratensis* area is located close to Ithaca in Tompkins County. Its soils are of glacial lake origin. They are described by Howe, Buckman, and Lewis (10). The *Poa compressa* province is located west of Rochester in Monroe County. Crabb, et al. (4) state that the soil (Ontario loam) resulted from the weathering of glacial till. Of the two soils, the Ontario loam (*Poa compressa*) province is generally recognized as the more extensive and valuable agriculturally.

Mordoff (16) supplies climatic data for both areas under the headings "Ithaca" and "Brockport." The mean annual precipitation is

[4]Commonly in New York State relatively small pastures are maintained near buildings for night grazing. This obviates the need for the farmer to drive cattle from a distant lot before the morning milking. Such night pastures are often more heavily grazed than day pastures and droppings are more abundant per unit area.

0.24 inch greater in the *Poa compressa* (Rochester) province; but the rainfall from May to September, inclusive, is 1.98 inch greater in the *Poa pratensis* (Ithaca) area. The significance of this difference may possibly be affected by the fact that night pastures of the *Poa compressa* area are dominantly *Poa pratensis*. There was a difference between areas of 0.71 inch in the lightest growing season rainfalls recorded. Mean annual relative humidity at 8 a.m. was about 4% higher in the Ithaca area. Mean annual temperatures differ by 0.2° F. Mean maximum and mean minimum growing season temperatures do not differ significantly. Thus, such a review of climatological data as is possible leaves one not at all certain that climate exerts the major influence on species dominance in these areas.

Nineteen pastures were found suitable for this study on the Dunkirk silty clay loam. The sward of each pasture was dominantly *Poa pratensis*, but numerous various sized patches of *Poa compressa* were always interspersed. These patches permitted the pairing of samples taken close to each other. Thus slope, degree of erosion, depth of surface soil, drainage, direction of exposure, and texture presented the external appearance of being very similar under the swards of the two grasses. No pairing was done unless closeness of grazing was identical. Care was taken to avoid spots influenced by the droppings of livestock. No patch of *Poa compressa* that was less than 5 feet in diameter was sampled, and in most cases the spots of this grass were much larger than that. No spot was considered to represent either species unless 80% or more of the vegetation (estimated) was made up of the grass under consideration. In no instance was a sample taken where a trace of clover could be found.

On the Ontario loam 20 pastures well suited to the investigation were located. In each case the sward was predominantly *Poa compressa*. The procedure was the same as that outlined above. Avoiding clover was less a problem in this area than in the *Poa pratensis* province.

METHODS

All samples were collected during June 1936. A soil auger was used and the hand employed as a sleeve in such a manner that almost none of the core of soil was lost. Because root penetration was abnormally deep in the more frequently plowed *Poa compressa* pastures, it was regarded advisable to sample uniformly to a depth of 6⅔ inches. The amount of sample depended on the number of opportunities for pairing. The aim was to collect 12 pairs from each pasture, and that objective was realized in all except three or four cases. In no instance were less than nine pairs taken. The borings collected from beneath each species were combined so that there resulted two composite samples from each pasture. Within a period of not over 4 hours from the time of collecting, each composite sample was spread out to air-dry. The dry soil was put through a sieve having circular perforations 1 mm in diameter and stored in stoppered wide-mouthed bottles.

The pH was determined potentiometrically with the quinhydrone electrode, employing a 1:1 soil-water suspension. Readings thus obtained were checked against a bubbling hydrogen electrode in the case of several samples which had a reaction of approximately pH 8.

Exchangeable hydrogen was determined by means of the unpublished method

of Merkle. Ten grams of soil and 50 cc of 10/N calcium acetate (previously adjusted to pH 6.99) were boiled for 5 minutes in a covered 150-ml beaker. Merkle found that boiling resulted in less drift and more accurate readings than could be expected when 72 hours were allowed for reaching equilibrium without heating. After cooling to room temperature, quinhydrone was added and the platinum electrode inserted directly into the beaker, thus forming a half-cell which was set up against the saturated calomel half-cell of the potentiometer. The resistance was then set at a voltage corresponding to pH 7.0 at the existing temperature. Standard lime-water was used to bring the suspension to a value of pH 7.0.

Fifty grams of soil were used for the determination of exchangeable bases. Neutral ammonium acetate was employed as the exchange solution. The amount required to give a calcium-free test for the percolate varied with the sample. The range was from 1,500 ml to 2,400 ml, the average being close to 1,700. From this point the method of determining bases was essentially that of Merkle (15), except that sodium, ammonium, and carbonates were not estimated.

"Available" phosphorus was estimated colorimetrically by the method of Dahlberg and Brown (5) modified according to suggestions of Merkle as follows: A quarter inch square of tinfoil was used instead of the tin rod. Eleven drops of acid solution of ammonium molybdate were used instead of 5 ml of Dahlberg and Brown molybdate reagent. This acid solution of ammonium molybdate was prepared by dissolving 25 grams of ammonium molybdate in 200 ml of distilled water at 60° C. The solution was then mixed with 800 cc of sulfuric acid. The latter had been prepared by diluting 250 cc of concentrated sulfuric acid to 800 and cooling. Distilled water was then used to bring the volume to 1 liter. The resulting solution was stored in a dated brown bottle. Color standards were prepared from potassium dihydrogen phosphate; fresh standards being made up for each group of six unknowns.

Total nitrogen was determined on hundred-mesh soil by the Gunning-Hibbard method modified to include nitrate nitrogen.

Student's method was used in the statistical treatment of the data resulting from the paired composite samples. Love's (12) modification of Student's table served as a basis for the computation of odds. Coefficients of correlation were computed by Spearman's method as outlined by Love (13).

DISCUSSION OF RESULTS

HYDROGEN-ION CONCENTRATION

Contrary to popular belief, the data presented in Tables 1 and 2 show that *Poa compressa* in this study dominates on the more nearly neutral soil type. The mean hydrogen-ion concentration difference between paired composite samples is 9.880×10^{-8} in the *Poa pratensis* area with odds of only 2.6 to 1 against this difference being due to chance alone. Where *Poa compressa* is the dominant grass the mean difference is 1.906×10^{-7} with odds of about 14 to 1. The mean hydrogen-ion concentration is higher in the *Poa compressa* samples from both provinces, but differences would not justify the conclusion that pH may explain species dominance.

REPLACEABLE HYDROGEN

The effect of replaceable hydrogen in any soil depends upon the total exchange capacity and the degree of saturation with cations

TABLE 1.—*Comparative analyses of soils under both species of Poa in the area of Poa pratensis domination.*

Pasture No.*	*Poa compressa*								*Poa pratensis*							
	M. E. per 100 grams of soil					Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.	M. E. per 100 grams of soil					Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.
	Ca	Mg	K	H	Approximate exchange capacity*				Ca	Mg	K	H	Approximate exchange capacity*			
1	3.45	0.75	0.08	1.88	6.16	69.54	5.70	20.0	2.67	0.68	0.24	2.48	6.06	59.05	5.33	20.0
2	5.18	0.94	0.35	1.00	7.47	86.66	6.12	30.0	5.45	1.21	0.37	1.95	8.97	78.26	5.80	30.0
3	3.71	0.50	0.12	1.63	5.95	72.66	5.70	20.0	3.28	0.52	0.22	1.95	5.97	67.33	5.61	30.0
4	4.69	0.73	0.28	0.98	6.68	85.38	5.93	20.0	4.07	1.70	0.55	1.10	7.41	85.23	6.15	30.0
5	3.10	0.50	0.07	2.02	5.68	64.50	5.46	10.0	4.68	0.70	0.35	1.52	7.25	79.06	5.81	30.0
6	3.64	0.58	0.34	1.82	6.38	71.44	6.00	50.0	4.38	0.60	0.40	1.66	7.04	76.45	6.03	50.0
7	3.81	0.37	0.05	0.87	5.09	82.97	6.14	20.0	4.08	0.45	0.11	0.98	5.62	82.63	6.18	10.0
8	4.84	0.49	0.09	0.48	5.89	91.90	6.81	50.0	4.58	0.46	0.14	0.61	5.79	89.51	6.76	50.0
9	2.60	0.29	0.14	2.03	5.06	59.93	5.50	20.0	3.42	0.41	0.02	1.67	5.52	69.75	5.62	30.0
10	3.65	0.17	0.10	2.26	6.17	63.47	5.25	10.0	3.75	0.20	0.25	1.44	5.64	74.45	5.56	20.0
11	2.53	0.50	0.20	2.21	5.44	59.39	5.44	5.0	2.83	0.52	0.24	2.73	6.33	56.82	5.36	5.0
12	1.73	0.60	0.60	1.37	4.29	68.18	6.20	50.0	1.72	0.56	0.52	1.43	4.22	66.10	6.26	70.0
13	2.91	0.69	0.24	1.50	5.34	71.98	5.62	5.0	3.94	0.87	0.24	1.53	6.58	76.79	6.05	10.0
15	6.89	1.79	0.24	sat.	8.91	sat.	6.65	10.0	5.47	1.14	0.31	0.65	7.58	91.41	6.48	20.0
16	3.83	1.21	0.19	0.90	6.13	85.33	6.33	10.0	3.49	1.24	0.22	1.17	6.12	80.85	6.26	20.0
17	4.33	1.47	0.51	1.24	7.54	83.61	6.28	10.0	4.77	1.46	0.56	1.19	7.98	85.06	6.52	10.0
Av.	3.81	0.72	0.22	1.48	6.14			21.25	3.91	0.80	0.28	1.50	6.51			27.19

*Samples Nos. 14, 18, and 19 lost in laboratory fire.
†Totals and averages based on data carried out three decimal places.

TABLE 2.—*Comparative analyses of soils under both species of Poa in the area of Poa compressa domination.*

Pasture No.*	*Poa compressa*								*Poa pratensis*							
	M. E. per 100 grams of soil					Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.	M. E. per 100 grams of soil					Approximate per cent saturation†	pH	Pounds of PO_4 per acre 2,000,000 lbs.
	Ca	Mg	K	H	Approximate exchange capacity*				Ca	Mg	K	H	Approximate exchange capacity*			
1	5.87	1.17	0.23	1.27	8.54	85.15	6.40	10.0	7.18	1.57	0.14	1.31	10.20	87.14	6.40	10.0
2	4.88	0.93	0.17	1.93	7.90	75.59	6.11	10.0	4.79	0.93	0.27	1.76	7.75	77.37	6.20	20.0
3	4.90	1.38	0.16	1.52	7.96	80.93	6.48	10.0	8.71	4.64	0.23	1.34	14.93	91.00	6.44	10.0
4	6.00	2.34	0.24	sat.	8.58	sat.	8.11	20.0	6.41	2.14	0.25	sat.	8.79	sat.	8.06	20.0
5	5.64	1.58	0.28	sat.	7.50	sat.	7.46	5.0	7.72	3.01	0.31	sat.	11.05	sat.	7.32	5.0
6	5.77	1.36	0.55	0.90	8.58	89.51	6.93	10.0	5.86	1.59	0.45	0.60	8.50	92.97	6.90	10.0
7	8.30	1.79	0.25	sat.	10.34	sat.	7.88	20.0	7.07	2.02	0.28	sat.	9.38	sat.	7.93	50.0
8	5.38	1.58	0.10	0.46	7.51	93.93	6.46	5.0	7.20	1.42	0.43	0.09	9.13	99.05	6.91	5.0
9	8.32	1.73	0.34	sat.	10.39	sat.	7.06	5.0	8.86	1.64	0.47	sat.	10.97	sat.	6.99	30.0
10	9.54	2.11	0.32	sat.	11.97	sat.	7.19	10.0	9.31	2.90	0.46	sat.	12.66	sat.	7.12	50.0
11	7.32	1.51	0.26	0.54	9.62	94.37	6.85	5.0	7.72	1.67	0.47	sat.	9.85	sat.	7.04	10.0
12	11.26	3.04	0.21	sat.	14.52	sat.	7.46	50.0	11.61	3.40	0.23	sat.	15.24	sat.	7.82	50.0
13	7.92	2.13	0.30	0.13	10.48	98.76	6.75	20.0	8.16	2.24	0.30	sat.	10.71	sat.	7.20	20.0
14	11.46	1.44	0.44	1.57	14.90	89.47	5.90	5.0	8.72	1.42	0.36	0.37	10.86	96.60	6.95	5.0
15	7.86	3.59	0.30	0.62	12.37	95.00	6.93	10.0	7.88	4.27	0.26	0.60	13.01	95.42	6.76	10.0
16	6.85	1.41	0.40	sat.	8.66	sat.	7.00	10.0	7.50	2.33	0.41	sat.	10.24	sat.	7.06	2.5
17	12.01	2.00	0.34	0.46	14.80	96.92	6.72	5.0	11.54	3.38	0.34	sat.	15.26	sat.	7.05	10.0
18	4.74	1.83	0.35	1.31	8.23	84.06	6.25	10.0	4.83	1.77	0.43	0.92	7.95	88.41	6.52	5.0
20	6.96	4.15	0.25	sat.	11.35	sat.	7.32	5.0	7.65	4.18	0.23	0.11	12.17	99.10	6.96	10.0
Av.	7.42	1.95	0.29	0.97	10.22			11.84	7.83	2.45	0.33	0.79	10.98			17.5

*Sample No. 19 lost in laboratory fire.
†Totals and averages based on data carried out three decimal places.

other than hydrogen. Thus, by itself, a figure representing replaceable hydrogen is somewhat incomplete. The writer did not determine replaceable hydrogen in anticipation that it would serve as a means of predicting where either species of Poa is especially adapted, but rather for the sake of completing the exchange picture of the soils.

The data show more replaceable hydrogen in soils taken from the *Poa pratensis* province than in those taken from the one where *Poa compressa* dominates; but again differences between paired samples within either province lack consistency. A mean difference of 0.121 M.E. with odds of approximately 6.5 to 1 is found for the area of *Poa pratensis* and a difference of 0.190 M.E. with odds of about 3.9 to 1 for the *Poa compressa* province. The mean replaceable hydrogen is higher under *Poa pratensis* in the area where that species dominates and higher under *Poa compressa* where it dominates.

The agreement between the pH data and those for replaceable hydrogen is indicated by highly significant coefficients of correlation. (See Table 3.)

TABLE 3.—*Correlation data.*

Correlation between	Coefficients			
	Area of *Poa compressa* dominance		Area of *Poa pratensis* dominance	
	P. compressa	*P. pratensis*	*P. compressa*	*P. pratensis*
Total nitrogen and approximate total exchange capacity	.576†	.949†	.272*	.664†
Total nitrogen and replaceable potassium	.095*	−.176*	.445*	.354*
Total nitrogen and sodium acetate soluble phosphate	−.170*	.144*	.275*	−.011*
pH and sodium acetate soluble phosphate	.353*	.397*	.315*	−.011*
pH and percentage saturation	.903†	.929†	.802†	.752†
pH and replaceable hydrogen	−.828†	−.789†	−.864†	−.646†
Replaceable calcium and sodium acetate soluble phosphate	.021*	.272*	.050*	−.135*
Replaceable magnesium and sodium acetate soluble phosphate	.257*	.050*	−.095*	−.177*

*Means not significant.
†Means highly significant.
Odds 99 to 1, or better.

REPLACEABLE CALCIUM

Failure to determine carbonates[5] influences the validity of the replaceable calcium figures, for, according to Kelley (11) and Gedroiz (8) carbonate calcium is probably available. For this reason the exchangeable calcium data should be regarded as approximate. Since all samples were leached until calcium tests were negative, it is likely that the data more nearly represent available than replaceable calcium.

The figures in Tables 1 and 2 show that the approximate replaceable calcium is generally higher in the province of *Poa compressa* domination than in the area where *Poa pratensis* holds the ascendency. In the former area, 14 of 19 pastures contained more approximate replaceable calcium under *Poa pratensis* than under *Poa compressa*. The mean difference between paired samples is approximately 0.41 M.E. with odds of 11 to 1. The mean difference between paired samples is approximately 0.11 M.E. in the *Poa pratensis* area, with odds of about 2½ to 1. Again in this instance the calcium mean is slightly higher under *Poa pratensis* than under *Poa compressa*.

REPLACEABLE MAGNESIUM

According to Crabb, *et al.* (4), some of the parent rock from which the glaciated Ontario loam was derived was Lockport limestone which is dolomitic. This suggested that if indeed one element might have a major influence on the incidence of either species, magnesium was a possibility. The work of MacIntire, Willis, and Hardy (14) indicated that magnesium carbonate, as such, is not a common constituent of humid region soils.

Tables 1 and 2 show that the area of *Poa compressa* domination is generally higher in exchangeable magnesium than that of *Poa pratensis*. However, within the province of *Poa compressa*, more exchangeable magnesium is found under *Poa pratensis*. Odds pertaining to the mean difference are at least 100 to 1 even when the somewhat dubious looking results of pasture No. 3 are included. (160 to 1 when No. 3 is excluded.) This relationship does not apply to the *Poa pratensis* province where the mean difference (in the same direction) is only about 0.07 M.E. and the odds are about 4 to 1.

One might only speculate as to causes of differences in the replaceable magnesium between paired samples of Ontario loam. Soil variation might have resulted from varying amounts of dolomitic material deposited in glacial debris. It is also possible that the replaceable magnesium was influenced by vegetation over a period of time. *Poa pratensis* makes a more dense sod than *Poa compressa*. The total nitrogen data support the suspicion that residues may be greater under *Poa pratensis*. Residue differences might explain differences in replaceable magnesium. Also livestock droppings of some earlier time may have an effect even though they no longer be visible. Merkle (15) was among those who showed that the use of manure increased exchangeable magnesium.

[5]Destruction of sample remnants in a laboratory fire made carbonate determinations impossible.

Not enough plant analysis data are available to show a trend in magnesium content characteristic of either species. The improbability that magnesium would be little depleted by a grass in a province where it does not dominate and more depleted by the same grass where it does dominate, leads one back to the hypothesis that the original soil material was different. This hypothesis is somewhat further supported by the data which show that approximate total exchange capacity is not generally greater where more replaceable magnesium is found in the *Poa compressa* province.

Another possible explanation is that replaceable magnesium is taken up less rapidly by the species under which more is found. This cannot be a species characteristic, for if that were the case one would expect the species to influence exchangeable magnesium in a similar direction on both soil types, which is not in accord with the data.

REPLACEABLE POTASSIUM

More consistent differences in exchangeable potassium exist between the paired samples of soils taken from beneath the two species in the province of *Poa pratensis* than between those taken where *Poa compressa* dominates. In the former area, the mean difference between paired samples is 0.071 M.E., the *Poa pratensis* soil being higher. The odds are about 105 to 1. Any attempt to explain why such a difference occurs can be no more than speculation. It is rather unlikely that the parent soil material was responsible because the Dunkirk silty clay loam was formed under glacial lake conditions (10).

As was pointed out in the case of magnesium, it is possible that livestock droppings of an earlier time or greater plant residues under *Poa pratensis* might be accountable for differences in replaceable bases. Also, if total nitrogen is assumed to correlate fairly well with organic matter and if decaying organic matter is assumed to affect the liberation of mineral soil potassium, one might expect total nitrogen to fluctuate with exchangeable potassium. That would involve ignoring plant removal and assuming that there is no difference between organic matter and actively decaying organic matter. The coefficients of correlation (Table 3) show that, despite all assumptions, there is no direct significant relationship between total nitrogen and replaceable potassium.

Differences between amounts of replaceable potassium found in the paired composite samples may be due to differences in the absorption of potassium by the Poa species. Herbage analyses reported by various investigators are not consistent enough to indicate that high potassium content is a species characteristic. The possibility of luxury consumption would lead one to expect no general agreement with respect to potassium in herbage analyses.

In the *Poa compressa* province the trend appears to be toward more replaceable potassium under *Poa pratensis*, but the mean difference is only 0.044 M.E. (Odds about 20 to 1.)

Unpublished observations of Cornell extension agronomists include cases of pastures that were dominantly *Poa compressa* being converted to dominantly *Poa pratensis* through the application of

manure. Unpublished research of Dr. J. A. Bizzell of Cornell University calls attention to the potassium content of this farm by-product. In his work manure was stored in lysimeters over a period of approximately 12 months. The drainage water from this manure was found to contain over three times as much potassium as nitrogen.

There is, no doubt, some difference between the soluble potassium of manure and the replaceable potassium of the soil. However, when one considers the above view points concerning manure along with the exchangeable potassium data, he is reluctant to generalize concerning the influence of potassium on the incidence of Poa species.

APPROXIMATE TOTAL EXCHANGE CAPACITY

The word "approximate" is used in connection with exchange capacity because sodium, ammonium, and carbonates were not determined. The exchange capacity figures which appear in Tables 1 and 2 were obtained by adding together the figures for the various bases. Mean approximate total exchange capacities are higher for *Poa pratensis* in both provinces. A mean difference of 0.759 M.E. with odds of about 14 to 1 is the result for the *Poa compressa* province; while the difference is 0.368 M.E. and odds about 27 to 1 where *Poa pratensis* dominates.

The data used in making Figs. 1 and 2 consistently show more total nitrogen under *Poa pratensis* than under *Poa compressa*. From this one might expect that the organic matter, represented in theory by the nitrogen, would mean higher exchange capacity. That total nitrogen and exchange capacity correlate is shown by coefficients of correlation appearing in Table 3. Note that the correlation is significantly positive except for the *Poa compressa* spots in the *Poa pratensis* province.

APPROXIMATE PERCENTAGE METALLIC BASE SATURATION

Pierre (18) suggested that saturation data might be more significant from the crop standpoint than those pertaining to hydrogen-ion concentration. This is more likely to be true when the data represent several soil types than when they are taken within one type. The results appearing in Tables 1 and 2 are decidedly conflicting. In the *Poa pratensis* area the mean difference between the percentages of saturation of soils from beneath the two species is 0.112 (odds less than 1 to 1).

On the other hand, the mean difference in percentage saturation is 2.176 and the odds over 300 to 1 in the *Poa compressa* area, the greater mean being under *Poa pratensis*. The soils of this area are relatively high in calcium and magnesium and most of them are "saturated" or nearly "saturated".

It is of interest to note the degree of positive correlation between pH and approximate base saturation. Highly significant coefficients are obtained for both grasses for both areas. These may be found in Table 3.

"AVAILABLE" PHOSPHATES

It was not possible to obtain reliable fertilizer histories of most pastures included in this study. Many of them probably never re-

ceived commercial fertilizer. However, pastures 3 to 12, inclusive, in the province of *Poa pratensis* domination were known to have received superphosphate within 5 years. It is probably not without significance that the *Poa compressa* soil samples from pastures Nos. 5, 10, and 11, and the *Poa pratensis* soil from pasture No. 11 were the lowest in "available" phosphates and highest in hydrogen-ion concentration of the soils in the treated group.

In the *Poa pratensis* province pasture No. 12 is located where a garden occurred about 5 years before the time of sampling. Pasture No. 6 was treated with superphosphate approximately a month before the date the samples were taken. These facts, together with the phosphate contents of the soils from the latter two pastures, indicate that the test employed reveals differences somewhat in line with treatment, in at least these two known cases.

From the data in Tables 1 and 2 one may calculate that the mean difference in phosphates between the paired samples from the *Poa pratensis* province is 5.94 pounds per 2,000,000 pounds of soil; the odds about 171 to 1. Where *Poa compressa* is the dominant grass, the mean difference is 5.65 pounds of PO_4 and the odds about 30 to 1. In both areas the greater mean amounts of PO_4 are found under *Poa pratensis*, but the differences were only slightly greater than the precision intervals of the determinations. Thus, the soil phosphate data appear to be in general agreement with plant analysis results published by most investigators working with the Poa species. Attention has been drawn to the probability of greater residues under the more dense sward of *Poa pratensis*. Plant residues could account for phosphate differences. These results, interpreted in the light of the above facts and postulates might help bear out the opinion of agronomists who believe that *Poa pratensis* requires a higher fertility level than *Poa compressa*.

Another supposition that one might make in an effort to explain the greater phosphate content of the soil under *Poa pratensis* is that that species did not take up phosphates to as great an extent as *Poa compressa*. Such a supposition would not be in agreement with plant analysis data.

TOTAL NITROGEN

Of the pastures studied, the only ones known to have received an application of manure within 10 years are Nos. 6, 7, 8, and 12 in the province of *Poa pratensis* domination and No. 4 in the province of *Poa compressa* domination. None of these was treated with manure within 2 years of the time of sampling and none proves to be especially high in total nitrogen. It has been observed by Cornell extension agronomists and by the writer that applications of manure to *Poa compressa* pastures tends to bring in *Poa pratensis*. This tendency is noticeable in *Poa compressa* pasture No. 4 where more than the usual amount of *Poa pratensis* is found.

No pasture included in this study is known to have received any commercial form of nitrogen with the single exception of *Poa pratensis* pasture No. 12, and it had not received commercial nitrogen within 5 years of the time of sampling. *Poa pratensis* pastures Nos. 3, 4, and 5

were seeded in 1931. The sweet clover which served as a nurse crop was grazed in 1932. The data show that these pastures are not perceptibly higher in total nitrogen than others where sweet clover had not been grown.

In the area of *Poa pratensis* domination the mean total nitrogen is 0.0321% higher under *Poa pratensis* than under *Poa compressa* (odds 3,332 to 1). Where *Poa compressa* dominates, mean total nitrogen is 0.0523% higher under *Poa pratensis* than under *Poa compressa* (odds infinite). Figs. 1 and 2 illustrate how consistent the nitrogen differences are.

Again the data appear to be in agreement with the majority of plant analysis figures to be found in the literature, and also in agreement with the views of numerous observers who have contended that *Poa pratensis* requires a higher fertility level than *Poa compressa*. The total nitrogen data also help make it possible for the writer to understand why there may be found in the *Poa compressa* province certain night pastures which are close to 100% *Poa pratensis*. However, it cannot be said from this investigation whether the total nitrogen figures, which in a general way reflect organic matter, should be interpreted to mean that nitrogen is responsible (together with phosphorus) for the incidence of *Poa pratensis*, or whether some property of the organic matter is accountable to a greater degree. One of these properties of the assumed organic matter is the moisture-holding capacity; another is its possible effect on soil temperature. Of course the moisture aspect of the problem would involve a subsoil study which has not been made.

The data do not enable one to distinguish between cause and effect. In other words they do not indicate whether total nitrogen directly contributes to influence the incidence of the Poas, or whether total nitrogen differences are the result of residues caused by unlike sod-forming habits of the two species.

Although no soil sample was taken where even so much as a trace of clover was visible, it cannot be said that clover had not occurred at some previous time in the patches, usually of *Poa pratensis*, where total nitrogen content is relatively high. The greater phosphate content of the *Poa pratensis* spots might easily have favored legume growth. What has been said about clover influence might also be said about feces and urine, although sampling patches 5 feet and more in diameter may make this supposition a little less likely.

The work of Skinner and Noll (20) which showed the influence of nitrogen on the transition from *Poa compressa* to *Poa pratensis* would lend weight to the belief that nitrogen had a causal effect. However, in the investigation of these workers, phosphorus and potash tended to bring about a similar transition. It is possible that the latter two elements accomplished this result indirectly through the stimulation of clover which was present under the conditions of their work.

SUMMARY

Thirty-nine New York pastures were chosen for study in two localities not vastly different in climate but distinctly unlike in soil. In the more agriculturally important Ontario loam area or province

Poa compressa is the dominant grass, while *Poa pratensis* holds the ascendency in the area on Dunkirk silty clay loam. Patches of the species other than the dominant one occurred in all pastures selected for study. This made possible the pairing of samples and the use of Student's method. This investigation considers soil differences beneath the two species of Poa, on which subject there are many opinions and few experimental data.

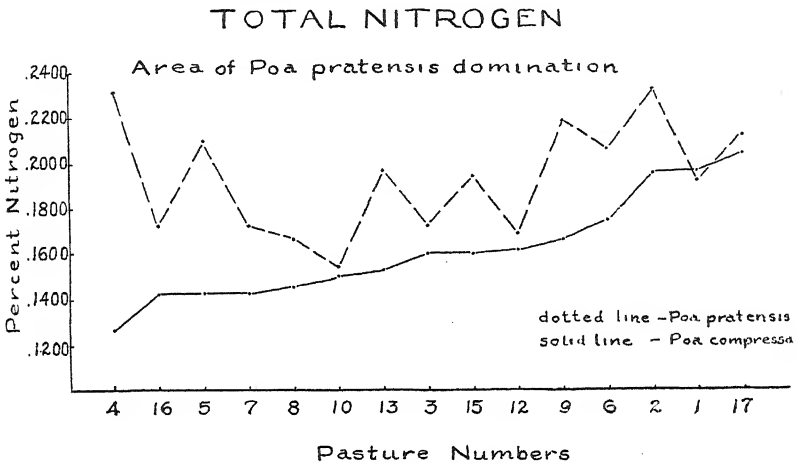

FIG. 1.

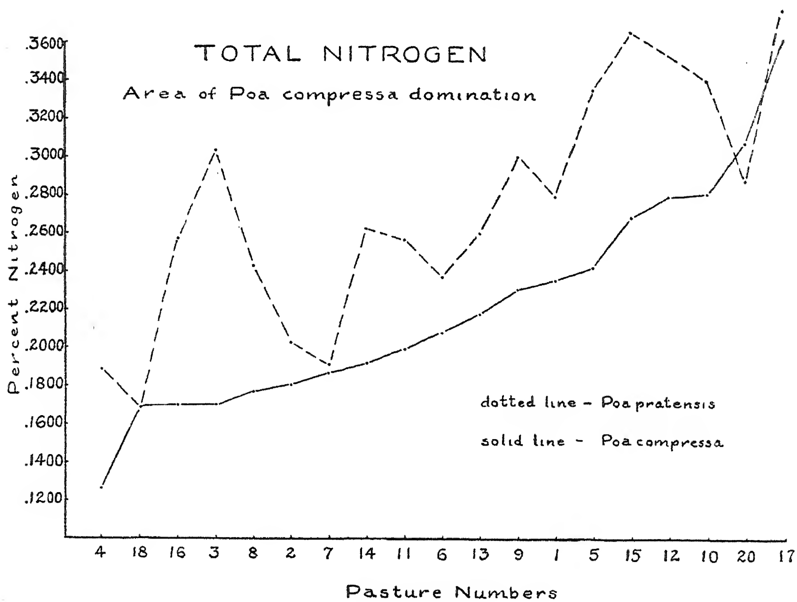

FIG. 2.

The hydrogen-ion concentration results support odds of about 2.6 to 1 and about 14 to 1, respectively, for the mean differences between the paired soil samples from beneath the two species in the *Poa pratensis* and *Poa compressa* provinces. Despite this, and contrary to popular opinion, *Poa compressa* dominates in the province of lower hydrogen-ion concentration (or higher pH).

Data for replaceable hydrogen agree generally with the pH figures as indicated by significant negative coefficients of correlation.

Odds for the mean differences in approximate replaceable calcium are about 6.1 to 1 and about 3.9 to 1 for the areas of the *pratensis* and *compressa* species, respectively. However, it is very evident from the data that *Poa compressa* dominates in the province the soil of which is generally higher in replaceable calcium.

Within the province of *Poa compressa* domination the means indicate more replaceable magnesium under the *pratensis* species than under *compressa*. Odds for the mean difference are at least 100 to 1. In the *Poa pratensis* province the mean difference (in the same direction) justifies odds of 4 to 1.

Mean differences in replaceable potassium seem, in a sense, to be the counterpart of those for magnesium. The higher odds (about 105 to 1) apply to the *Poa pratensis* province. Odds for the *Poa compressa* area are about 20 to 1. In both cases the means are higher under the *pratensis* species.

Differences between approximate total exchange capacity means yield odds of about 27 to 1 and about 14 to 1 for the areas of *Poa pratensis* and *Poa compressa*, respectively. A high degree of positive correlation exists between total nitrogen and approximate total exchange capacity except for the *Poa compressa* soils taken in the *Poa pratensis* area.

Mean approximate metallic base saturation is higher for soils beneath the *pratensis* species than beneath those of the *compressa* in the area where the latter is dominant. Odds for the mean difference are over 300 to 1. In the *Poa pratensis* area the odds are less than 1 to 1. There is a high degree of positive correlation between pH and metallic base saturation.

More "available" phosphates are generally found under the *pratensis* in both provinces, but the mean differences are only slightly greater than the precision intervals of the determinations. Odds are about 171 to 1 and 30 to 1 for *Poa pratensis* and *Poa compressa* areas, respectively.

Infinite odds and odds of about 3,332 to 1 between means for the areas of *Poa compressa* and *Poa pratensis*, respectively, indicate that greater amounts of total nitrogen are found under *Poa pratensis*.

LITERATURE CITED

1. Bauer, F. C., and Snider, H. J. A year's progress in solving farm problems in Illinois. Ill. Agr. Exp. Sta. 48th Ann. Rpt. 1936.
2. Cooper, H. P. Relation of hydrogen ion concentration of soils to the growth of certain pasture plants. Plant Phys., 7:527–532. 1932.
3. ———, Wilson, J. K., and Barron, J. H. Ecological factors determining the pasture flora in northeastern United States. Jour. Amer. Soc. Agron., 21:607–627. 1929.

4. CRABB, G. A., CARR, M. E., GILBERT, B. D., and BOUYOUCOS, G. J. Soil survey of Monroe County, N. Y. U. S. D. A. Bur. Soils. 1912.
5. DAHLBERG, H. W., and BROWN, R. J. A study of the Neubauer and Winogradsky (azotobacter) methods as compared with a chemical method for the determination of phosphate deficiency in western soils. Jour. Amer. Soc. Agron., 24:460–468. 1932.
6. DIX, W. Untersuchungen über die Leistungen der schleswigholsteinischen Dauerweide und deren Abhängigkeit vom Boden, Grasnarbe, und den klimatischen Faktoren. Landw. Jahrb., 76:525–574. 1932.
7. FRAPS, G. S. Relation of the water-soluble potash, the replaceable, and acid soluble potash to the potash removed by crops in pot experiments. Texas Agr. Exp. Sta. Bul. 391. 1929.
8. GEDROIZ, K. K. Exchangeable cations of the soil and the plant: I. Relation of certain cations fully saturating the soil exchange capacity. Soil Science, 32:51–64. 1931.
9. HOAGLAND, D. R., and MARTIN, J. C. Absorption of potassium by plants in relation to replaceable, non-replaceable, and soil solution potassium. Soil Science, 36:1–32. 1933.
10. HOWE, F. B., BUCKMAN, H. O., and LEWIS, H. G. Soil survey of Tompkins County, New York. U. S. D. A. Bur. Soils. 1924.
11. KELLEY, W. P. The agronomic significance of base exchange. Jour. Amer. Soc. Agron., 22:977. 1930.
12. LOVE, H. H. A modification of Student's table for use in interpreting experimental results. Jour. Amer. Soc. Agron., 16:68–72. 1924.
13. ————. Application of Statistical Methods to Agricultural Research. Shanghai, China. The Commercial Press Ltd. 1936. (Spearman's method p. 161, Table XI p. 490, and Table III p. 472.)
14. MACINTIRE, W. H., WILLIS, L. G., and HARDY, J. I. The non-existence of magnesium carbonate in humid soils. Tenn. Agr. Exp. Sta. Bul. 107. 1914.
15. MERKLE, F. G. Base exchange studies on the Pennsylvania Jordan field plots. Soil Science, 38:37–64. 1934.
16. MORDOFF, R. A. The climate of New York State. Cornell Univ. Agr. Exp. Sta. Bul. 444. 1934.
17. OLSEN, CARSTEN. Studies of the hydrogen-ion concentration of the soil and its significance to the vegetation, especially to the natural distribution of plants. Compt. Rend., Lab. Carlesberg 15:1–166. 1923.
18. PIERRE, W. H. Hydrogen-ion concentration, aluminum concentration in the soil solution, and per cent base saturation as factors affecting plant growth on acid soils. Soil Science, 31:163–207. 1931.
19. SALISBURY, E. J. The incidence of species in relation to soil reaction. Jour. Ecol., 13:149–160. 1925.
20. SKINNER, J. J., and NOLL, C. F. Botanical composition of a permanent pasture as influenced by fertilizers of different compositions. Soil Science, 7:161–175. 1919.
21. STEIGER, T. L. Structure of prairie vegetation. Ecology, 11:180–217. 1930.
22. WHEETING, L. C. A study of methods for the determination of the available potassium in soils. Soil Science, 29:1–20. 1930.

IMPROVEMENT OF *ANDROPOGON SCOPARIUS* MICHX. BY BREEDING AND SELECTION[1]

KLING ANDERSON AND A. E. ALDOUS[2]

ANDROPOGON SCOPARIUS is widely distributed over the temperate portion of North America, its range, according to Hitchcock (6),[3] extending from Quebec and Maine to Alberta and Idaho and from there southward to Florida and Arizona. It is of major importance, however, only in the tall grass or true prairie region. Weaver and Fitzpatrick (12) rate it as the second most important species of the prairie, second only to *Andropogon furcatus*. These two species make up approximately half the total vegetative cover of the Flint Hill or bluestem pasture region, which is the only remaining large area of these grasses.

Drought and overgrazing have so seriously depleted the ranges that it is now necessary that something be done to restore them. To this end the plant breeder can play an important part in the production of superior strains. Before this can be done, however, knowledge of the variability and inheritance of the characters with which he is to work must be available. To this end, studies of *Andropogon scoparius* were started in 1935 by the Agronomy Department of Kansas State College.

REVIEW OF LITERATURE

Andropogon scoparius, like many other species, is extremely variable, being made up of a number of habitat types corresponding to Turesson's (11) ecotypes. Gregor and Sansome (4) conclude that there exist within a species definite habitat types and agree with Turesson that these types represent the genotypical response of the species-population to a definite habitat. They further state that there may be phenotypic uniformity within these habitat types without complete genotypic similarity; or in the words of Turesson (10), "The habitat type, even if it appear to be quite homogeneous in its habitat, is made up of a number of individuals, none of which may represent the genotype of another".

Jenkin (7) in his work with *Lolium perenne* has noted that individual plants differ from one another even when derived from a relatively stable habitat, but that this variation is usually within quite narrow limits, while plants from different habitats conform to different general types.

The behavior of its chromosomes at meiosis may afford some explanation of the variability of *Andropogon scoparius* within these habitat types. Church (3) reports that this species is an octoploid having the unusual chromosome complement of 21 bivalents and 14 univalents. During the metaphase of the first division, the univalents may be seen lagging in contrast with the bivalents all at the plate, and in the partly completed anaphase it can be seen that many of them never reach the plate. The diad stage may be observed with extrusions of chromatin stranded in the space between the separating halves of the mother cell. Bivalents

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[2]Assistant professor of pasture management and former professor of pasture management (deceased), respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 869.

may occasionally lag with the univalents in the homeotypic division. The distribution of the univalents to the two daughter cells is random.

Selfing apparently reduces the set of seed in this species just as it does in a number of other grasses that have been studied. Beddows (1) obtained 22.3 times as many seeds from open-pollinated heads of *Festuca elatior* as from those enclosed in selfing bags. Hayes and Barker (5) found low seed set in selfed heads of timothy. Jenkin (7) not only found a reduction in seed set but found many highly self-sterile plants of *Lolium perenne*. He believes that this self-sterility is one of the greatest obstacles in the way of improvement of grasses.

The vigor of open-pollinated crops is generally depressed in the generations following inbreeding. Jenkin (7) found that cross-fertilization gave an increase of 37 to 224% in productivity over the inbred progenies in *Lolium perenne*. Other workers reporting losses in vigor due to inbreeding are Calder (2) in orchard grass, Lewitsky (8) in timothy and red clover, Nilsson-Leissner (9) in red fescue (*Festuca rubra*), and Williams (13) in red clover. Williams showed that some families do not suffer so great losses of vigor as do others. These are valuable for the production of improved strains because they tend to be strongly prepotent for high yielding qualities when outcrossed. He suggests that linked groups of growth factors, inherited as units, may account for the prepotence of some plants.

MATERIALS AND METHODS

Three generations of *Andropogon scoparius* have been included in this study. The first generation, set out in 1935, consisted of 180 plants selected as the most desirable of several hundred seedlings. In a sense this first generation represented the variations that occur in the bluestem pasture region, yet in reality some selection had already been practiced, for the seed from which this generation was grown came from the best plants in the older observation plats of the grass nursery. These in turn had been grown from the seed of particularly promising plants occurring in nature.

The second generation consisted of progeny of each of these plants, while the third generation consisted of progeny of approximately 50 of the best second generation plants. The three generations shall be referred to as the 1935, the 1936, and the 1937 nurseries, respectively.

Each generation of seedlings has been grown in the greenhouse from late February until May when they were transplanted to the nursery. The plants have all been spaced 30 inches in each direction in order that they might attain their full development reasonably unhampered by the competition of neighboring plants, and that they might easily be observed and studied. This spacing also permits easy cultivation with a small horse-drawn cultivator and permits furrow irrigation during the drier months of the summer.

The plants have been carefully observed during the growing season and detailed field notes have been taken. On the basis of these observations the outstanding plants have been selected each year to be the maternal parents of the next generation. A number of heads on each of several particularly promising plants have been bagged so that the effect of selfing might be observed. These heads mature within the bags and are harvested in October at the same time the open-pollinated seed is gathered.

Germination tests have been made during February. The 1936 seed was germinated on moist filter paper in Petri dishes. This gave somewhat higher germination percentages than in the field, so the 1937 seed was germinated on soil in the

greenhouse to simulate natural conditions. It was placed on moist soil and covered with a quarter of an inch of clean sand. After germination counts had been made the seedlings were spaced in greenhouse flats, later to be moved to the nursery.

EXPERIMENTAL RESULTS

GENERAL VARIABILITY

In such a widely distributed species as *Andropogon scoparius* extensive variations are expected to occur. There seem to be rather definite habitat types, corresponding to Turesson's (10) ecotypes, that have arisen as a result of natural selection over long periods of time. Habitat types from North Dakota, Nebraska, Kansas, Oklahoma, and Texas have been grown and observed in the nursery. In general the northern types are earlier, smaller, and less leafy than those from the south. In the 1937 season the average heading date of plants from northern Nebraska was 17 days earlier than that of plants from Manhattan, Kansas, while Oklahoma plants headed 10 days later than those from Manhattan. Variations equally as great are seen in leafiness and plant size. Figs. 1, 2, and 3 serve to illustrate this.

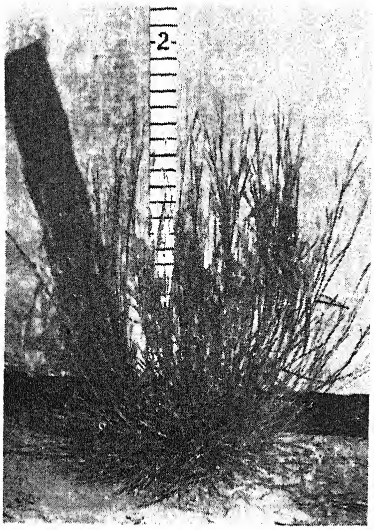

FIG. 1.—*Andropogon scoparius* grown at Manhattan, Kansas, from northern Nebraska seed. Photographed Oct. 6, 1937.

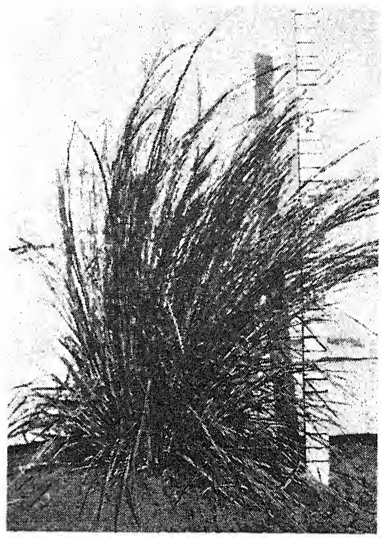

FIG. 2.—*Andropogon scoparius* grown at Manhattan, Kansas, from local seed. Photographed Oct. 6, 1937.

It is not meant to imply that there is complete uniformity within the habitat types, but simply that the variation between types is greater than that within types. When the habitat types are studied more closely they are found to be quite variable within themselves, certain characters such as leafiness, time of maturity, plant height, and seed set, showing wide variations.

LEAFINESS

Since it is the leafy portion of the grass plant that is preferred by the grazing animal, the area of leaf surface may be considered one of the most important factors of quality. On this assumption leaf area has been used as one of the bases of comparison. It is the most important single consideration in the selection of desirable types.

Leaf areas were calculated for individual plants by multiplying average length of leaf by average width, by average number of leaves per culm, by total number of culms per plant. This gave a value slightly greater than actual leaf area but which was found to be quite satisfactory for purposes of comparison.

The plants have been found to vary greatly in total leaf area. Table 1 shows the leaf areas of the 1937 crop of the three generations.

If this variability in leaf area is due to the genetic constitution, as the results of selection indicate, it may be used as a basis of improvement. The leafy types may be isolated and made uniform by selection and inbreeding, then if necessary they may be blended into strains by hybridization.

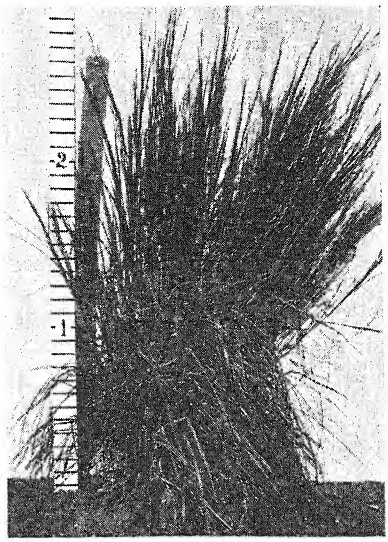

FIG. 3.—*Andropogon scoparius* grown at Manhattan, Kansas, from Oklahoma seed. Photographed Oct. 6, 1937.

TABLE 1.—*Leaf areas per plant (in sq. cm.) of three generations of Andropogon scoparius, measurements taken June, 1937.*

Season of growth	Leaf area in sq. cm.	
	Range	Average and standard deviation
3rd (1935 nursery)	14,000–45,000	30,700±7,500
2nd (1936 nursery)	2,000–24,000	10,000±3,700
1st (1937 nursery)	1,000–15,000	6,500±2,400
1st (1937 nursery—selfed)	1,000–11,000	6,400±2,200

Selection tends to decrease the variability of leaf area in *A. scoparius*. Variations of leaf areas within groups of progeny of individual plants have been found by analysis of variance to be significantly less than the variations between these groups. In these analyses the F values of 3.74 and 7.30 were obtained in the second and third generations, respectively, while the 1% level of significance was only 2.00. This indicates that the variability is actually due, in large part,

to genetic differences in the plant and that improvement can be brought about by selection and breeding.

BASAL DIAMETER, PLANT HEIGHT, AND TIME OF MATURITY

Other variable characters have been found to respond to selection in the same manner as does leaf area. The variations within progeny of single selected individuals have been compared by analysis of variance with the variations between these groups of progeny in the following characters: Basal diameter of plant, plant height, and time of maturity. In each of these characters selection has significantly reduced the variability within groups of progeny. This reduction in variability was particularly pronounced in time of maturity. The average heading date of the second generation (1936 nursery) was August 8 ± 13 days. The next generation, selected for late maturity, headed on September 5 ± 5 days. In both generations variability was significantly less within progeny groups than between them, the F values being 3.20 and 13.37 for the second and third generation, respectively. The 1% level of significance was 2.00. It will be seen that selection not only reduced variability but changed the time of maturity in the desired direction.

SEED SET

Seed set in *Andropogon scoparius* has been studied on the basis of the percentage of spikelets that produce caryopses. Variability has been noted in this character, the average seed set of open-pollinated plants being $63.12 \pm 18.7\%$ for the third generation. A great reduction in seed set has been observed when the heads are enclosed in any sort of bag for the purpose of self-fertilization. Under such conditions the seed set was only $6.7 \pm 5.3\%$. It has not been definitely determined, but it is believed that this reduction in seed set is due to the abnormal conditions existing within the selfing bag. It was noted that in bags which had accidentally been torn or had been injured by grasshoppers there was practically a normal set of seed. It was impossible to determine whether or not the bags had been torn before pollination had taken place, so the plants may or may not actually have been selfed.

GERMINATION

This character is important because of the obvious relationship it bears to securing stands. As a rule the germination of *A. scoparius* is fairly high but considerable variation has been observed, as shown in Table 2.

TABLE 2.—*Germination percentages of A. scoparius, 1937 nursery, 1937 crop.*

Year	Pollination method	Germination percentage
1936	Open-pollinated	63.5 ± 13.4
	Selfed	25.8 ± 23.4
1937	Open-pollinated	18.5 ± 12.8
	Selfed	30.5 ± 24.4

The high germination percentages obtained for the 1936 seed, especially the open-pollinated seed, was thought to be due to the fact that the seeds were germinated in the laboratory on moist filter paper, so the 1937 crop was germinated on soil to simulate natural conditions. The germination of the open-pollinated seed was significantly decreased, but there is no way of explaining the fact that there was no corresponding decrease in the case of the selfed seed. Tests of several generations may be necessary to make this clear.

INTERRELATIONSHIPS OF CHARACTERS

It has been observed that rather definite interrelationships exist between certain characters and that they follow definite trends. Table 3 is a summary of these interrelationships.

TABLE 3.—*Correlation coefficients for the interrelationships existing between certain characters of A. scoparius based on data from the 1937 crop of three generations of plants.*

Character observed	Generation in nursery	Number of culms per plant	Height of plant	Leaf area	Time of maturity
Basal diameter of plant	1935 1936 1937	.25±.06 .52±.04 .68±.03	.69±.04 .40±.05 .51±.04	.24±.06 .50±.04 .67±.04	——— ——— ———
Number of culms per plant	1935 1936 1937	——— ——— ———	——— ——— ———	.46±.12 .79±.02 .87±.01	——— ——— ———
Height of plant	1935 1936 1937	——— ——— ———	——— ——— ———	.56±.10 .43±.04 .31±.05	——— ——— ———
Leaf area	1935 1936 1937	——— ——— ———	——— ——— ———	——— ——— ———	.26 ±.05 .18 ±.06 .003±.05

Two factors may be considered to influence these trends, the effect of selection and the effect of the age of the plant, that is, changes brought about during its life cycle. The two effects, however, can not be separated on the basis of the available data.

EFFECTS OF SELF-FERTILIZATION

The data available on the effect of selfing *A. scoparius* are too limited to furnish conclusive evidence. Approximately 50 plants were grown in the 1937 nursery from selfed seed and the evidence from these indicates that selfing has no deleterious effect on any of the characters, except seed set, and its effect on this character is probably due to the abnormal growing conditions existing within the selfing bag. Leaf area, basal diameter, plant height, and germination were not significantly different in the selfed plants when compared with the open-pollinated ones. Should it be shown conclusively that selfing does not reduce vigor in *A. scoparius*, it will prove a valuable method of breeding.

SUMMARY AND CONCLUSIONS

1. *Andropogon scoparius* in nature is an extremely variable species, divided into rather definite habitat types (the ecotypes of Turesson), which, however, exhibit considerable variability within themselves. In general, northern types are earlier, less leafy, and smaller than types from farther south.

2. Leaf area is the best single measure of quality and yield of forage. Wide variations in total leaf areas exist that are due to genetic differences in the plant. This is shown by the fact that the progeny of individual plants vary significantly from the progeny of other plants. The variability between these groups is greater than the variability within them. This indicates that selection, even in open-pollinated populations, tends to increase uniformity.

3. No satisfactory measure of quality has yet been devised. Grazing tests are probably the best measure and shall be applied before final selection of strains is made.

4. Basal diameter of the plants varies widely, yet there is a tendency toward uniformity within groups of progeny of individual plants.

5. Plant height has not been an important factor in selection of superior types of plants, yet studies indicate it to be definitely influenced by genetic make-up. There is a marked uniformity within the progeny of selected plants.

6. It is indicated that time of maturity can be changed by selection. This will make it possible to produce a strain that heads later, hence gives a longer summer grazing season. It is important that time of maturity be as late as possible, yet not so late that plants are frosted before producing seed.

7. Seed set is reduced by selfing in *Andropogon scoparius*. It is not definitely known whether this reduction in seed set is due to genetic causes or to abnormal conditions within the selfing bags.

8. There is no evidence to indicate that selfing has any effect on germination for selfed seed has been found to have as high germination percentages as that from open-pollinated plants.

9. Differences have been observed in rate of germination. It is important that grasses should germinate quickly in order that the seedling plant become established before summer droughts. Seedlings that become established quickly are better able to compete with weeds and other grasses.

10. Rather definite relationships have been found to exist between certain characters in *Andropogon scoparius*, and that these relationships follow definite trends is indicated as follows:

(a) Basal diameter is correlated positively with number of culms, with a tendency for the correlation to be higher in younger plants.

(b) Basal diameter is also correlated positively with plant height but no trends can be observed. Since these characters are expression of general vigor their high positive correlation is in accordance with expectations.

(c) Basal diameter and leaf area are positively correlated, the highest correlation existing in young plants.

(d) Height of plant and leaf area, while positively correlated, exhibit the highest correlation in older plants. Evidence indicates, however, that the low correlation in the third generation may be due to the effect of selection rather than to age of plants.

(e) In general, late plants tend to be leafier than early plants. After two generations of selection, however, no correlation exists between these two characters.

11. The limited amount of evidence on the effect of self-fertilization indicates that the vigor of *Andropogon scoparius* is not seriously, if at all, affected by inbreeding.

LITERATURE CITED

1. Beddows, A. R. Seed setting and flowering in various grasses. Welsh Plant Breeding Sta. Bul. H, 12:5–99. 1931.
2. Calder, J. W. Methods employed in the breeding of pasture plants. Imp. Bur. Plant Genetics (Aberystwyth) Bul. 11: 63. 1933.
3. Church, G. L. Meiotic phenomena in certain Gramineae. II. Paniceae and Andropogoneae. Bot. Gaz., 88:63–84. 1929.
4. Gregor, J. W., and Sansome, F. W. Experiments on the genetics of wild populations. I. Grasses. Jour. Gen., 17:349–364. 1927.
5. Hayes, H. K., and Barker, H. D. The effects of self-fertilization on timothy. Jour. Amer. Soc. Agron., 14:289–293. 1922.
6. Hitchcock, A. S. Manual of grasses of the United States. U. S. Dept. Agr. Misc. Pub. 200. 1935.
7. Jenkin, T. J. Self- and cross-fertilization in *Lolium perenne*. Jour. Gen., 17:11–17. 1926.
8. Lewitsky, G. A. The karyotype in systematics. Bul. Appl. Bot., 27:187–240. 1931. (Russian-English summary.)
9. Nilsson-Leissner, G. Preliminary inbreeding experiments in red fescue. Hereditas, 18:115–121. 1933.
10. Turesson, G. The genotypical response of the plant species to the habitat. Hereditas, 3:211–350. 1922.
11. ———. The species and variety as ecological units. Hereditas, 3:100–113. 1922.
12. Weaver, J. E., and Fitzpatrick, T. J. Ecology and relative importance of the dominants of the tall grass prairie. Bot. Gaz., 93:113–150. 1932.
13. Williams, R. D. Heterosis in red clover. Effect of inbreeding in F_2 and F_3 populations. Welsh Jour. Agr., 13:172–190. 1937.

EFFECT OF SEED DISINFECTION AND DELAYED SOWING ON THE CONTROL OF BUNT IN INFESTED SOIL[1]

J. Foster Martin[2]

CONSIDERABLE infestation by bunt spores (*Tilletia tritici* (Bjerk.) Wint. and *T. levis* Kühn) sometimes occurs in the soils of the Columbia Basin region, although the introduction of resistant varieties of wheat and more efficient seed treatment methods have significantly reduced the hazard from bunt. Susceptible varieties frequently develop 1 to 10% or more of infected heads when sown in fields in which the soil is infested with bunt spores despite the use of clean and carefully disinfected seed.

In dry years, there is not sufficient soil moisture to germinate all soil-borne bunt spores before the desirable time for fall sowing arrives, although occasionally the soil may be moist enough to sprout wheat. Bunt infection usually is low in wheat sown early when the soil temperature is high. Some farmers in districts of eastern Oregon where bunt infection is unusually heavy take advantage of this situation and sow wheat before fall rains begin, in spite of the hazard of thin stands that may result from the consequent deep sowing in a dry seedbed. If, by delaying sowing for 2 or 3 weeks after the advent of fall rains, soil infestation could be reduced sufficiently for bunt infection to be controlled by seed disinfection, the improvement in stands and better control of weeds as compared with early dry seeding should be of material benefit to farmers. With this in mind, experiments were begun at Pendleton, Ore., in 1931 to determine (a) the relative efficiency of certain seed disinfectants in preventing infection from bunt in the soil, and (b) the length of time sowing must be delayed after the beginning of favorable moisture conditions in the fall to permit the germination and destruction of sufficient soil-borne bunt spores so that resulting infection will be at a minimum. Results of 4 years' experiments are reported here.

REVIEW OF LITERATURE

As early as 1907, Sutton and Pridham (9)[3] noted the value of copper sulfate in protecting seed from recontamination by soil-borne bunt spores. Heald, Zundel, and Boyle (5) stated that 3 ounces of copper carbonate per bushel gave equal or better protection than copper sulfate, but that 2 ounces was not quite so effective. Leukel (7) and Heald and Gaines (4) concluded that these two disinfectants were about equal in fungicidal value. In the experiments of Twentyman (10), however, copper sulfate was superior to copper carbonate in preventing reinfection. Twentyman treated the seed and then re-inoculated it before sowing. In the experiments of Sutton and Pridham (9), Heald, Zundel, and Boyle (5), Heald and Gaines (4),

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[3]Figures in parenthesis refer to "Literature Cited", p. 876.

Twentyman (10), and Leukel (7), formaldehyde gave slight or no protection from reinfection in the soil.

Mackie (8) stated that a minimum of about 14% of soil moisture was necessary for the germination of bunt spores in the soil at Davis, Calif. Heald and Gaines (4) observed that no bunt developed with 12% moisture at Pullman, Wash. However, as noted by the same authors (8, 4), soil may be moist enough to sprout wheat although too dry to germinate the bunt spores. Hungerford (6) and Heald and Gaines (4) reported that in the soils of the Palouse section the optimum soil moisture content for bunt infection was about 25%. Woolman and Humphrey (13) and Leukel (7) call attention to the inhibiting effect of a saturated soil on the germination of bunt spores.

Twentyman (11) reported low percentages of bunt in wheat sown early when the soil was still warm. Woolman (12) found that a practically bunt-free crop was produced when the soil temperature was above 65° F, that the percentage of bunt increased as the temperature fell from 60° to 45° at which point it was highest, and that the infection decreased below 40°. Similar conclusions were drawn by Heald and Gaines (4). According to Faris (2), a temperature of 41° to 59° F is well within the range of high infection. Hungerford (6) obtained the most infection with a temperature of 48° to 54° F. Aamodt (1) and Leukel (7) observed the greatest infection when the soil temperature was 50°. Leukel obtained no infection from *Tilletia tritici* with a soil temperature above 59° and none from *T. levis* above 68°.

According to Hungerford (6), bunt spores which had been in moist cultivated soil for 1 month had practically lost their viability. Heald (3) stated that spores lose their power to infect after 50 to 60 days in moist soil. Woolman and Humphrey (13) found that spores in moist soil lost their infective properties in 30 to 60 days.

MATERIALS AND METHODS

Heavy soil infestation was obtained by scattering 30 grams of bunt spores (*Tilletia tritici* and *T. levis*) per 8-foot row in open furrows, and then mixing the spores with the surface 2 inches of soil. The first sowing was made immediately, after which the entire plat was thoroughly watered. An attempt was made to maintain the soil moisture at approximately 25%, but precipitation on several occasions increased the soil moisture to a point probably above the optimum for bunt infection.

Soil temperature records were kept during the fall of 1934, and they agreed well with the air temperatures except that they did not fluctuate so much or drop so low. The air temperature records seem adequate for explaining certain of the fluctuations in infection data.

All of the materials used for treatment were standard seed disinfectants with the exception of the ethyl mercury iodide. This substance as applied contained 5% of the volatile compound ethyl mercury iodide. Unless otherwise stated, the seed was disinfected 24 hours before sowing.

A single 8-foot row of each treatment was sown on each date and clean seed of the Hybrid 128 variety of wheat was used in all experiments.

RESULTS OBTAINED

RELATIVE EFFECTIVENESS OF SEED DISINFECTANTS

As shown in Table 1 no seed treatment controlled bunt entirely except in two very late plantings in 1934–35 when infection in the untreated rows was less than 5%. The best treatments greatly re-

TABLE 1.—*Bunt infection in Hybrid 128 wheat grown from seed treated with various disinfectants and sown at intervals in soil artificially inoculated with bunt spores in four crop years.*

Date		Seed treatment and bunt infection								
Sown	Emerged	Check, not treated, bunted heads, %	New Improved Ceresan		Ethyl mercury iodide		Copper carbonate		Copper sulfate* bunted heads, %	Formaldehyde† bunted heads, %
			Rate per bu., oz.	Bunted heads, %	Rate per bu., oz.	Bunted heads, %	Rate per bu., oz.	Bunted heads, %		
				1931–32						
Oct. 3	Oct. 13	15.7	—	—	—	—	4	7.6	—	—
Oct. 12	Oct. 21	73.3	—	—	—	—	4	58.8	—	—
Oct. 19	Oct. 29	75.6	—	—	—	—	4	62.4	—	—
Oct. 27	Nov. 5	77.7	—	—	—	—	4	71.1	—	—
Nov. 4	Nov. 15	36.4	—	—	—	—	4	3.7	—	—
Nov. 12	Nov. 27	13.1	—	—	—	—	4	1.1	—	—
Average		48.6	—	—	—	—	—	34.1	—	—
				1933–34						
Nov. 3	Late winter	89.9	3	18.8	—	—	4	62.5	56.8	50.7
Nov. 8	Late winter	93.5	3	33.9	—	—	4	58.9	61.4	57.8
Nov. 17	Late winter	93.2	3	40.7	—	—	4	68.3	63.4	73.7
Nov. 23	Late winter	88.8	3	—	—	—	4	51.9	—	—
Average‡		92.2	—	31.1	—	—	—	63.2	60.5	60.7
				1934–35						
Sept. 19	Sept. 30	11.6	3	10.1	—	—	3	11.2	—	24.9
Sept. 26	Oct. 5	46.8	3	4.9	—	—	3	22.6	—	44.7
Oct. 3	Oct. 14	27.2	3	1.3	—	—	3	32.7	—	24.6
Oct. 10	Oct. 24	60.1	3	1.9	—	—	3	45.8	—	55.4
Oct. 17	Oct. 29	43.6	3	17.4	—	—	3	26.8	—	47.4
Oct. 24	Nov. 7	50.3	3	14.4	—	—	3	32.1	—	33.5
Oct. 31	Nov. 15	40.1	3	18.0	—	—	3	31.6	—	41.4
Nov. 8	Dec.	10.1	3	6.3	—	—	3	3.7	—	9.3
Nov. 15	Dec.	4.2	3	0	—	—	3	4.7	—	0
Feb. 27	Mar. 23	0	3	0	0	—	3	0	—	0
Average		29.4	—	7.4	—	—	—	21.1	—	28.1

1935–36

Sept. 20	Sept. 27	26.7	½	18.1	½	5.5	3	11.3	—	34.3
Sept. 20	Sept. 27	—	1	14.0	1	17.6	—	—	—	—
Sept. 20	Sept. 27	—	2	10.3	2	9.3	—	—	—	—
Sept. 30	Oct. 8	72.5	½	32.5	½	40.0	3	69.8	—	51.1
Sept. 30	Oct. 8	—	½§	35.2	½§	49.0	—	—	—	—
Sept. 30	Oct. 8	—	1	33.6	1	35.3	—	—	—	—
Sept. 30	Oct. 8	—	1§	36.2	1§	47.1	—	—	—	—
Sept. 30	Oct. 8	—	2§	25.5	2§	46.0	—	—	—	—
Oct. 9	Oct. 19	55.5	½	30.7	½	35.4	3	39.1	—	53.5
Oct. 9	Oct. 19	—	½§	27.2	½§	27.2	—	—	—	—
Oct. 9	Oct. 19	—	1	26.3	1	38.0	—	—	—	—
Oct. 9	Oct. 19	—	1§	35.1	1§	49.4	—	—	—	—
Oct. 9	Oct. 19	—	2§	38.8	2§	49.4	—	—	—	—
Oct. 20	Dec. 8	70.2	½	36.1	—	—	3	71.4	—	—
Oct. 20	Dec. 8	—	1	32.0	—	—	—	—	—	—
Nov. 11	Jan. 10	49.6	½	8.5	—	—	3	27.6	—	—
Nov. 11	Jan. 10	—	1	7.8	—	—	—	—	—	—
Nov. 23	Jan. 10	7.3	½	2.0	—	—	3	2.7	—	—
Nov. 23	Jan. 10	—	1	1.7	—	—	—	—	—	—
Average‖		51.6	—	27.1¶	—	27.0¶	—	40.1	—	46.3

*One pound of copper sulfate to 5 gallons of water, followed by a lime bath.
†Solution made up of 1 part formaldehyde to 384 parts water.
‡Data not included from rows sown on Nov. 23.
§Seed treated on Sept. 19.
‖Computed from data from first three seedings only.
¶Average for ½-ounce rate of application.

duced the bunt in some of the sowings. The quantity of inoculum in the soil was extremely heavy and better control with fungicides might have been obtained under natural "smut-shower" conditions. No data on this point were obtained in these experiments, however.

New Improved Ceresan was significantly superior to the other standard seed disinfectants in controlling bunt in each of the 3 years they were tested. At the ½-ounce rate of application usually recommended for New Improved Ceresan, the reduction in bunt infection compared with the check in 1935–36 was 47.5%.

Ethyl mercury iodide controlled bunt about as well as New Improved Ceresan when sowing was not delayed. It reduced the average infection by 47.7% in 1936, when applied at ½ ounce per bushel. This compound is more volatile than New Improved Ceresan, however, and a distinct decline in effectiveness was noted when 10 days had elapsed between seed treatment and sowing.

Results with copper carbonate and copper sulfate agree in general with those of other investigators. The average reduction in bunt infection by copper carbonate was 29.8, 31.5, 28.2, and 22.3 percent, respectively, for the 4 years of the trial. Four ounces per bushel were applied in 1931–32 and 1933–34, but only 3 ounces per bushel were used the last 2 years. A 2-ounce rate was not included in these tests, as other trials have shown that this is not sufficient to control bunt consistently in a susceptible winter wheat variety in eastern Oregon.

Copper sulfate was tested only in the year 1933–34, but it reduced infection 34.4% compared with 31.5% for copper carbonate in the same year.

Formaldehyde controlled bunt approximately as well as copper carbonate and copper sulfate in 1933–34, but these results were not substantiated in the next two seasons. Formaldehyde reduced the average infection by 34.2, 4.4, and 10.3%, respectively, in the 3 years. The reason for the better control in 1933–34 is not known, but it occurred in all three dates of sowing that year. Emergence was slow and temperatures were equally favorable for high infection in all cases.

New Improved Ceresan was applied at several rates. As stated above, bunt infection was reduced 47.5% by the ½-ounce rate. The infection was reduced 52.3% when 1 ounce per bushel was used. On the average, the 2-ounce rate was superior to the lighter applications, but this rate sometimes is injurious to germination. When applied at 3 ounces per bushel in 1933–34 and 1934–35, it reduced infection 66.3 and 74.8%, respectively, calculated on the basis of infection in the untreated rows as 100%. Unless growing conditions are particularly favorable, however, this heavy rate of application causes a marked reduction in the germination of wheat. There is some, though probably not significant, evidence that New Improved Ceresan applied to the seed became less effective against soil-borne bunt spores when sowing was delayed unduly after treatment. At the 1-ounce rate of application, the crop from seed treated 3 weeks before sowing contained 35.1% of bunted heads compared with 26.3% from seed sown 24 hours after treatment and at the ½-ounce rate there was 30.7 and 27.2% of infection, respectively, from delayed and immediate sowing.

EFFECT OF DELAYED SOWING ON BUNT INFECTION

In three of the four seasons (Table 1) bunt infection was low in both treated and untreated wheat sown the day the soil was inoculated, although moisture and temperature were favorable for moderately high infection. Bunt infections were much higher in the second sowings made 7 to 10 days later. They continued to be high in the later sowings, with some fluctuation, until 30 to 50 days had elapsed after the soil was inoculated. In wheat sown after this period the bunt infection was low in both treated and untreated rows.

In 1933–34, the first sowing was made November 3 and the last sowing on November 23. All plants emerged during the late winter. Bunt infection was uniformly high in the untreated wheat sown on all four dates, and that treated with New Improved Ceresan had 18 to 40% of bunted heads. At the time of the sowing on November 3 temperatures apparently were low enough to favor a high bunt infection. Several weeks were required for the plants to emerge, but this may not have been a factor, as Faris (2) and Leukel (7) found a negative correlation between days from sowing to emergence and the percentage of bunt in the crop.

In 1931–32, there was a decided decrease in the percentage of bunt in the wheat sown 32 days after inoculation of the soil compared with that sown earlier. The percentage decrease was even greater for the sowing made 40 days after inoculation. The proportion of the decrease resulting from loss of spore viability cannot be determined, however, as a part may be attributed to lower temperatures.

Percentages of infection fluctuated considerably in 1934–35, but the irregularities approximately followed deviations of temperature. During the period between October 3 and 14 the mean air temperature was high, ranging from 46° to 63° F, and wheat sown October 3 had a low bunt infection. A drop in infection not explainable by temperature was shown in the untreated check sown 42 days after soil inoculation, but this drop did not occur in the treated rows. However, the sowing made 8 days later, or 50 days after soil inoculation, showed distinctly less infection. In this case, the temperature did not fall below 40° F for nearly 3 weeks after the wheat had been sown. Seed sown 7 days later on November 15 produced only 4.2% bunt in the untreated check.

In 1935–36, there was a sharp drop in infection in the sowing made 52 days following inoculation of the soil, and in the wheat sown 64 days after inoculation the infection dropped to 7.3% in the untreated check.

The seasonal trend in bunt infection in treated and untreated wheat was very similar. In 1931–32, there was only 15.7% bunt in the untreated check from the first sowing, but this increased to 73.3% in the second date, although moisture and temperature conditions remained about the same.

SUMMARY

The results of 4 years' experiments on the control of bunt (*Tilletia* spp.) in wheat sown in artificially infested soil are presented.

New Improved Ceresan was superior to the other standard seed disinfectants tested. When applied at 3 ounces per bushel it reduced infection 66.3 and 74.8%, based on infection in the untreated checks as 100%. A 3-ounce rate sometimes caused a marked reduction in stand. Bunt was reduced 47.5 and 52.3%, by ½-ounce and 1-ounce rates of application, respectively. There was no consistent loss in effectiveness when the seed was treated 3 weeks before sowing.

Ethyl mercury iodide was about equal to New Improved Ceresan when the grain was sown 24 hours after treating, but there was a distinct decline in effectiveness when 10 days elapsed between treating and sowing.

Copper carbonate and copper sulfate were equally effective in controlling infection by spores in the soil. Copper carbonate reduced bunt in the crop 22.3 to 31.5% in the 4 years.

Results in one year indicated that under certain conditions formaldehyde may be as effective as copper carbonate and copper sulfate, but in two other years formaldehyde reduced infection only 4.4 and 10.3%.

Percentages of bunt were significantly lower when the wheat was sown the day the soil was inoculated and watered than when sown a week or 10 days later.

Under the conditions of this experiment, between soil inoculation and sowing 50 to 60 days usually were required before sufficient spores were destroyed to eliminate danger from heavy infection. Low temperatures, however, occasionally prevented heavy infection. Low percentages of infection were obtained in untreated checks sown 60 days or more after the soil was inoculated with bunt spores. The seasonal trend in bunt infection in treated and untreated wheat was very similar.

LITERATURE CITED

1. AAMODT, O. S. Varietal trials, physiologic specialization, and breeding spring wheats for resistance to *Tilletia tritici* and *T. levis*. Canad. Jour. Res., 5:501–528. 1931.
2. FARIS, JAMES A. Factors influencing the infection of wheat by *Tilletia tritici* and *Tilletia laevis*. Mycologia, 16:259–282. 1924.
3. HEALD, F. D. Introduction to plant pathology. New York: McGraw-Hill Book Company, Inc. 1937.
4. ———, and GAINES, E. F. The control of bunt or stinking smut of wheat. Wash. Agr. Exp. Sta. Bul. 241. 1930.
5. ———, ZUNDEL, G. L., and BOYLE, L. W. The dusting of wheat and oats for smut. Phytopath., 13:169–183. 1923.
6. HUNGERFORD, CHAS. W. The relation of soil moisture and soil temperature to bunt infection in wheat. Phytopath., 12:337–352. 1922.
7. LEUKEL, R. W. Studies on bunt, or stinking smut, of wheat and its control. U. S. D. A. Tech. Bul. 582. 1937.
8. MACKIE, W. W. Seed treatment for the prevention of cereal smuts. Calif. Agr. Exp. Sta. Circ. 214. 1919.
9. SUTTON, G. L., and PRIDHAM, J. T. The effects of some fungicides recommended for the prevention of "stinking" smut (bunt) on the germination of wheat seeds. Agr. Gaz. N. S. Wales, 18:235–253. 1907.
10. TWENTYMAN, R. L. Experiments on the control of "stinking" smut or bunt. Jour. Dept. Agr. Victoria, 29:201–208. 1931.

11. ———. Experiments on the control of "stinking" smut or bunt. Part 2. Tests of the dry copper powders. Jour. Dept. Agr. Victoria, 29:235–248. 1931.

12. WOOLMAN, H. M. Stinking smut of wheat. Wash. Agr. Exp. Sta. Pop. Bul. 73. 1914.

13. ———, and HUMPHREY, H. B. Studies in the physiology and control of bunt, or stinking smut, of wheat. U. S. D. A. Bul. 1239. 1924.

COMPARISON OF DIFFERENT METHODS OF INOCULATING OAT SEED WITH SMUT[1]

R. W. Leukel, T. R. Stanton, and Harland Stevens[2]

FREQUENT failure to obtain high percentages of smutted plants in oat varieties and crosses that are not immune from or even highly resistant to smut is one of the principal difficulties encountered in the study of seed treatments and physiological races of oat smuts and in the development of smut-resistant varieties. This applies particularly to studies in which the seed is sown outdoors, because soil conditions immediately after sowing may be highly unfavorable to smut infection or development. When plants are grown in the greenhouse, moisture and temperature conditions may be adjusted and controlled so as to be optimum for smut infection, and high percentages of smutted plants are more easily obtained.

A number of investigators have described experiments in which the hulls of the oats were removed before applying the smut spores in order to insure a high percentage of infection. There are several objections to this method of inoculating oats, the chief one being the time and labor involved in removing the hulls. Both Johnston (3)[3] and Tapke (7) found that removing the hulls from naturally inoculated seed greatly reduced the amount of smut resulting from this naturally acquired inoculum, especially under field conditions. Stanton, *et al.* (6) reported that removing the hulls caused also an appreciable reduction in the percentage of emergence and in the percentage of plants reaching maturity.

In recent experiments by Leukel (4) the use of the spore-suspension-vacuum method as described by Haaring (2) resulted in relatively high percentages of infection. This method of applying spores to the seed involves but little labor, the seed is not injured, and the spores are placed under the hulls where, according to Gage (1), they may germinate and bring about infection in a manner similar to that supposedly obtaining in naturally inoculated seed.

The experiments here described were conducted at Arlington Farm, Arlington, Va., and at the experiment station at Aberdeen, Idaho. They were designed chiefly to compare the infection results following the application of dry smut spores to hulled[4] seed with those following the application of spores by the spore-suspension-vacuum method to unhulled seed of a highly susceptible, a moderately susceptible, and, in one case, a resistant variety. Other methods of inoculation were included as checks. Because loose smut (*Ustilago avenae* (Pers.) Jensen) and covered smut (*U. levis* (Kell. and Sw.) Magn.) are similar in their life histories, no attempt was made in these experiments to distinguish between the two species.

[1]Cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Idaho Agricultural Experiment Station. Received for publication July 28, 1938.

[2]Associate Pathologist, Senior Agronomist, and Assistant Agronomist, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 881.

[4]By the term "hulled" seed is meant seed with the hulls removed, while "unhulled" seed refers to seed from which the hulls were not removed.

MATERIALS AND METHODS

Varieties used.—Iogold, moderately susceptible to smut, and Victory, extremely susceptible, were used throughout the experiments. In the first experiment the resistant variety Markton also was included.

Smut used.—In 1936 a collection of loose smut (*Ustilago avenae*) from Ames, Iowa, was used. In 1937 a mixture of loose and covered smuts was used. The smut material was sifted through a 60-mesh sieve and stored at 10° C. Germination tests in 2% dextrose solution were made to determine the viability of the spores before the smut was used for inoculation.

Methods of inoculation.—Three methods of inoculation were used. In using the dry-spore method, the hulled or unhulled seed was dusted with a relatively large quantity of dry spores and then sifted to remove the excess spore material. In using the spore-suspension method, 2 grams of smut spores were added to a liter of 2% dextrose solution and the mixture was thoroughly shaken to get the spores into suspension. From 200 to 300 grams of seed were immersed in this liter of liquid for 20 minutes, the vessel being shaken at intervals to keep the spores and seed in suspension. The liquid was then drained off and the seed was spread out to dry for several hours. It was then placed in a chamber at 18° to 20° C and a relative humidity of 80 to 90% for 20 hours after which it was aired and stored until sowing time.

The procedure followed in the vacuum method was identical with that described for the spore-suspension method except that the liquid with the seed immersed in it was subjected to about 30 inches of vacuum during the period of immersion.

Sowing.—At Aberdeen, Idaho, the seed was sown in the field in 5-foot rows at the rate of 20 seeds per row. At Arlington Farm the seed was sown 1½ inches deep in small metal boxes containing soil adjusted to a moisture content of 60% of its water-holding capacity. These boxes, placed in larger covered boxes containing moist blotters to prevent the soil from drying, were kept in a chamber at 20° C until the plants emerged. At this time they were removed to the greenhouse and kept there until the plants were large enough to be transplanted.

In the first experiment at Arlington Farm the seedlings were transplanted to the greenhouse bench and in the second they were transplanted to outdoor beds. The seedlings were spaced 2 inches apart in both experiments.

Recording smut data.—Smut infection was recorded on the basis of both number of plants and number of heads. Only the percentages of plants infected are presented here. The percentages of smutted heads were generally somewhat lower than the corresponding percentages of smutted plants. Since plants having only a part of the heads infected were recorded as infected plants, one reason for this difference is apparent. Plants that failed to produce heads were not included in the tabulation.

EXPERIMENTAL RESULTS

In the first experiment (1936) at Aberdeen, Idaho, the resistant variety Markton showed no smutted panicles, regardless of the manner of inoculating the seed. The plants grown from inoculated hulled seed were, on the whole, less vigorous than those grown from unhulled seed similarly inoculated. It is unfortunate that smut-free hulled and unhulled seed were not included for comparison.

The results with Iogold and Victory are shown in Table 1. In five of the eight trials, dusting hulled seed with spores resulted in the

TABLE 1.—*Emergence, final stand, and smut infection in spring-sown oats grown from hulled and unhulled seed inoculated with smut spores and grown at Aberdeen, Idaho, and Arlington Farm, Va., 1936 and 1937.*

Year	Condition of seeds	Method of inoculation	Iogold No. seeds planted	Iogold Emergence %	Iogold Final stand %	Iogold Infection %	Victory No. seeds planted	Victory Emergence %	Victory Final stand %	Victory Infection %
		Aberdeen, Idaho (Planted and Grown in Field)								
1936	Unhulled	Dry spores	100	—	72	21.0	100	—	63	6.4
1936	Unhulled	Spore suspension	100	—	80	26.2	100	—	61	37.7
1936	Unhulled	Spore suspension (in vacuum)	100	—	79	39.2	100	—	67	64.1
1936	Hulled	Dry spores	100	—	59	61.0	100	—	74	89.1
1936	Hulled	Spore suspension	100	—	48	35.4	100	—	74	72.0
1936	Hulled	Spore suspension (in vacuum)	100	—	61	37.7	100	—	54	61.0
1937	Unhulled	Dry spores	300	—	35	8.5	300	—	47	29.3
1937	Unhulled	Spore suspension	300	—	38	8.8	300	—	45	48.5
1937	Unhulled	Spore suspension (in vacuum)	300	—	38	42.5	300	—	45	88.1
1937	Hulled	Dry spores	600	—	31	36.2	600	—	30	75.8
		Arlington, Va. (Planted and Grown Indoors)								
1936	Unhulled	None	100	92	88	0.0	100	68	67	0.0
1936	Unhulled	Dry spores	510	92	74	27.4	510	78	71	69.9
1936	Unhulled	Spore suspension	510	88	71	35.2	510	75	64	83.8
1936	Unhulled	Spore suspension (in vacuum)	510	76	46	64.2	510	67	38	91.3
1936	Hulled	None	100	66	44	0.0	100	72	64	0.0
1936	Hulled	Dry spores	510	11	5	66.7	510	18	18	94.5
1936	Hulled	Spore suspension	510	15	12	36.7	510	32	18	92.3
1936	Hulled	Spore suspension (in vacuum)	510	21	14	43.1	510	40	20	92.2
		Arlington, Va. (Planted Indoors, Matured in Outdoor Beds)								
1937	Unhulled	None	100	71	70	1.4	100	36	36	0.0
1937	Unhulled	Dry spores	400	84	83	52.7	400	60	56	82.1
1937	Unhulled	Spore suspension	400	76	74	54.5	400	45	43	91.8
1937	Unhulled	Spore suspension (in vacuum)	400	56	51	87.2	400	36	31	95.1
1937	Hulled	None	200	30	27	0.0	100	40	40	5.0
1937	Hulled	Dry spores	1,600	15	10	81.9	1,656	10	8	98.4

highest percentages of infected plants, the average percentages of infection for all trials being 61.5 and 89.5 for Iogold and Victory, respectively, compared with 58.3 and 84.7%, respectively, for the vacuum method of inoculation applied to unhulled seed. Inoculating the unhulled seed with dry spores resulted in a relatively lower percentage of infection in all cases. Hulling and smutting the seed, however, usually resulted in very poor stands. Only 16%[5] of all the hulled smutted seeds planted in the four experiments produced mature plants, while 44% of the unhulled vacuum-inoculated seeds produced plants that reached maturity. The corresponding figure for unhulled seed dusted with spores is 64% and that for unhulled seed inoculated with a spore-suspension without vacuum is 59%. It is evident therefore, that the severe infection brought about by forcing the smut spores under the hulls of the seed also may result in somewhat reduced stands, but the reduction is not so great as that resulting from hulling and smutting the seed.

It should be borne in mind that in the two experiments at Arlington Farm the soil conditions immediately after planting were nearly optimum for smut-spore germination and for infection of the seedlings (5); therefore, these results differ somewhat from those obtained in the field, especially in the marked reduction in emergence from the heavily smutted hulled seeds.

DISCUSSION

The relatively high percentages of smutted plants obtained as a result of using the spore-suspension-vacuum method for inoculating unhulled seeds, along with the ease and simplicity of this method as compared with the laboriousness of the hulling process, suggests it as a logical method for inoculating large numbers of seeds. Furthermore, since the seed inoculated by this method is not so severely injured as it is by hulling and applying dry spores, it produces a better stand and a population from which probably more reliable data can be secured in genetic studies.

SUMMARY

Studies on the relative merits of different methods of inoculating seed of oats with smut seem to show the following:

1. Immersing the seed in a smut-spore suspension under vacuum may result in infection percentages as high as those resulting from hulling the seed and dusting it with spores.
2. Inoculation by the latter method in addition to being extremely laborious may cause a severe reduction in emergence and stand, even in smut-resistant varieties.
3. The suspension-vacuum method offers a quick and effective way of inoculating large numbers of oat seeds with spores of loose or covered smut.

LITERATURE CITED

1. GAGE, G. R. Studies on the life history of *Ustilago avenae* (Pers.) Jensen and of *Ustilago levis* (Kell. and Swing.) Magn. Cornell Univ. Agr. Exp. Sta. Mem. 109. 1927.

[5]Weighted average.

2. HAARING, F. Eine Infektionsmethode für Haferflugbrand (*Ustilago avenae* Jens.) und ihre Anwendung zu Beiz—und Immunitätsversuchen im Laboratorium und Feld. Bot. Arch., 29:444–473. 1930.
3. JOHNSTON, C. O. Effects of soil moisture and temperature and of dehulling on the infection of oats by loose and covered smuts. Phytopath., 17:31–36. 1927.
4. LEUKEL, R. W. Seed treatment experiments with oats naturally and artificially inoculated with smuts. U. S. D. A. Tech. Bul. 568. 1937.
5. REED, GEORGE M., and FARIS, J. A. Influence of environal factors on the infection of sorghums and oats by smuts. II. Experiments with covered smut of oats and general considerations. Amer. Jour. Bot., 11:579–599. 1924.
6. STANTON, T. R., F. A. COFFMAN, V. F. TAPKE, G. A. WIEBE, R. W. SMITH, and B. B. BAYLES. Influence of hulling the caryopsis on covered-smut infection and related phenomena in oats. Jour. Agr. Res., 41:621–633. 1930.
7. TAPKE, V. F. The influence of seed hulling on loose smut in naturally inoculated oats. Phytopath., 26:588–596. 1936.

AGRONOMIC AFFAIRS

ANNUAL MEETING OF SOCIETY

THE thirty-first annual meeting of the American Society of Agronomy will be held in the Mayflower Hotel, Washington, D. C., Wednesday, Thursday, and Friday, November 16, 17, and 18.

ANNUAL MEETING OF SOIL SCIENCE SOCIETY OF AMERICA

THE annual meeting of the Soil Science Society of America will be held at the Mayflower Hotel, Washington, D. C., Wednesday, Thursday, and Friday, November 16, 17, and 18. Tentative programs have been arranged for three sectional sessions morning and afternoon of the first day, a joint session with the American Society of Agronomy on the morning of the second day, and two sectional sessions on the afternoon of the second and morning and afternoon of the third day. The dinner and business meeting of the Society is scheduled for the evening of November 16.

MEETING OF WESTERN BRANCH OF SOCIETY

THE Western Branch of the American Society of Agronomy held its twenty-second annual meeting at the University of Arizona at Tucson August 31 to September 2. The first two days were devoted to the presentation of formal papers and the third day to inspection trips to the Soil Conservation Service Nursery at Tucson, the U. S. Field Station at Sacaton, and the Salt River Valley Experiment Farm at Mesa. Attendance ranged from 28 to 45.

Officers for 1939 were elected as follows: For President, Dr. R. J. Evans, Utah Experiment Station, Logan, Utah; and for Secretary, Coit A. Suneson, Division of Cereal Crops and Diseases, Davis, Calif.

SECTIONAL PUBLICATION OF "BIOLOGICAL ABSTRACTS" DECIDED UPON

BEGINNING with 1939 it will be possible not only to subscribe to BIOLOGICAL ABSTRACTS as a whole but also to obtain separate sections of BIOLOGICAL ABSTRACTS at a reduction in cost as compared with the subscription price for the complete ABSTRACTS. At the same time the ABSTRACTS will retain its entity

by continuous pagination of the volume and a complete index. This index will be supplied to each subscriber, thus assuring full covering of the biological sciences.

Without repaging or other change, except in the cover, it is proposed to break up the ABSTRACTS into the following subject groups or parts for 1939:

I. General Biology, including general biology, biography-history, history, bibliography, evolution, cytology, genetics, biometry, and ecology. Price, $4.

II. Experimental Animal Biology, including animal physiology, nutrition, pharmacology, pathology, anatomy, embryology, and animal production. Price, $9.

III. Microbiology and Parasitology, including immunology, bacteriology, viruses, parasitology, protozoology, and helminthology. Price, $5.

IV. Plant Sciences, including phytopathology, plant physiology, plant anatomy, paleobotany, systematic botany, agronomy, horticulture, forestry, pharmacognosy, and pharmaceutical botany. Price, $6.

V. Animal Sciences, including paleozoology, parasitology, protozoology, helminthology, systematic zoology, and economic entomology. Price, $6.

The subscription price for the complete volume for 1939 will be $25 to individual subscribers and institutions alike. Based on the experience of the past year, prompt coverage in 1939 is anticipated with a lag of not more than two or three months and with the index appearing in the spring. In order to facilitate plans for 1939, subscription blanks will soon be distributed to members of societies constituting the Union as well as to libraries and institutions.

NEWS ITEMS

J. D. GUTHRIE, formerly County Agent of Goochland County, Virginia and who spent last year at Cornell University where he received his M.S. degree in agronomy has been employed as Assistant Extension Agronomist, Virginia Polytechnic Institute, Blacksburg, Va.

D. D. MASON, who received his M.S. degree in agronomy in June 1938, has been employed as Assistant Agronomist by the Virginia Agricultural Experiment Station and assigned to soil survey field work.

DR. J. R. TAYLOR, JR., formerly Associate Soil Chemist, Alabama Experiment Station, has been appointed Agronomist for the Virginia-Carolina Chemical Corporation, Richmond, Virginia.

A CHAPTER of the Society of Sigma Xi will be installed at the University of Florida, Friday, October 28.

ROY W. SIMONSON and ROBERT W. PEARSON have been appointed Assistant Professors in the Agronomy Department at Iowa State College. Dr. Simonson will be associated with the soil survey and land use program in Iowa and Dr. Pearson will undertake research and teaching in soil fertility.

Doctor T. L. Lyon, formerly head of the Department of Argonomy, Cornell University and a charter member and Historian of the American Society of Agronomy, died at his home in Ithaca October 7.

The death of Professor John B. Wentz of the Department of Farm Crops, Iowa State College, occurred the latter part of September.

Doctor C. R. Burnham, University of West Virginia, was appointed Associate Professor in the Division of Agronomy and Plant Genetics, University of Minnesota, beginning September 1.

Lewis C. Saboe, a graduate of South Dakota State College, has accepted a teaching assistantship in agronomy and plant genetics, University of Minnesota.

David Reid has resigned as Assistant in Agronomy and Plant Genetics, University of Minnesota, to become Agent in Wheat Investigations with headquarters at Amarillo, Texas.

Among the new graduate students in Agronomy and Plant Genetics, University of Minnesota, are I. M. Atkins, U. S. Dept. of Agriculture, Denton, Texas; D. C. Tingey, Utah Agricultural Experiment Station, Logan, Utah; L. L. Robertson, Dominion Department of Agriculture, Calgary, Alberta, Canada; Wm. Semeniuk, Howard B. Peto, and J. R. Weir, University of Alberta, Canada; and H. T. Yang and K. W. Wang from China.

ERRATUM

In the article on "Effectiveness of Spraying with Fertilizers for Control of Weeds on Arable Land" by B. N. Singh and K. Das, appearing on pages 465 to 474 of the current volume of the Journal the following corrections should be made: The first citation to literature on page 465 should be to a paper by B. N. Singh, K. Das, and G. V. Challam on "Effectiveness of Cultural Treatments in the Control of Weeds," Empire Jour. Exp. Agr., 5: 63–68. 1937. Also, in Table 3 on page 469 "*A. album*" should read "*A. arvensis*."

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MINOR ELEMENTS AND MAJOR SOIL PROBLEMS[1]

L. G. WILLIS AND J. R. PILAND[2]

RESEARCH in soil fertility has been based largely upon the principle of limiting factors which implies that crop production is governed by the supply of that essential element which is furnished in the least fraction of the amount required for maximum growth. It is further assumed that the functions of these elements are in a major degree independent and additive.

The need for supplying nitrogen, phosphorus, potassium, lime, and organic matter to soils has been recognized for over a century. Minor elements, such as boron, copper, magnesium, and manganese, have been more recently added to the list of supposedly essential elements. When a response to any of these minor elements has been demonstrated, it has been assumed that this constitutes proof of a specific deficiency and that it is only necessary to add a compound containing the respective element to an otherwise adequate fertilizer to produce satisfactory results.

Such concepts do not always conform to the evidence. Before pointing out some of the inconsistencies of current ideas, however, it is desirable to introduce a discussion of fundamental logic.

PRINCIPLES OF LOGIC

The successive steps in research as it is applied to soil fertility can be presented diagramatically as in Fig. 1. The initial undertaking is that of assembling original observations and data. These may be formal or informal, exactly quantitative or only approximately so. From them, by a process of induction, a theory is developed. Then, by deduction, a number of independent objective tests are devised, each designed to produce evidence by which the validity of the basal theory can be judged. It is not logical to use the data from which a theory is derived as supporting evidence. Ultimate proof of any conclusion may be impossible, but approximate proof is assumed when

[1]Paper read before Section O (Agriculture) of the American Association for the Advancement of Science, Indianapolis, Ind., Dec. 28, 1937. Published by permission of the Director of the North Carolina Agricultural Experiment Station as paper No. 104 of the Journal Series. Received for publication August 1, 1938.

[2]Soil Chemist and Assistant Soil Chemist, respectively.

no objective test fails to support the theory. A theory is acceptable as truth, therefore, only when it cannot be disproved. At any time, a single contradictory observation will necessitate some degree of modification.

The misuse of statistical methods of analysis of data frequently leads to erroneous conclusions. In an experiment to determine the potassium requirements (for example) of a crop on a soil of any given category, it is customary to determine the significance of the differences in yield of crops produced by various amounts and sources of

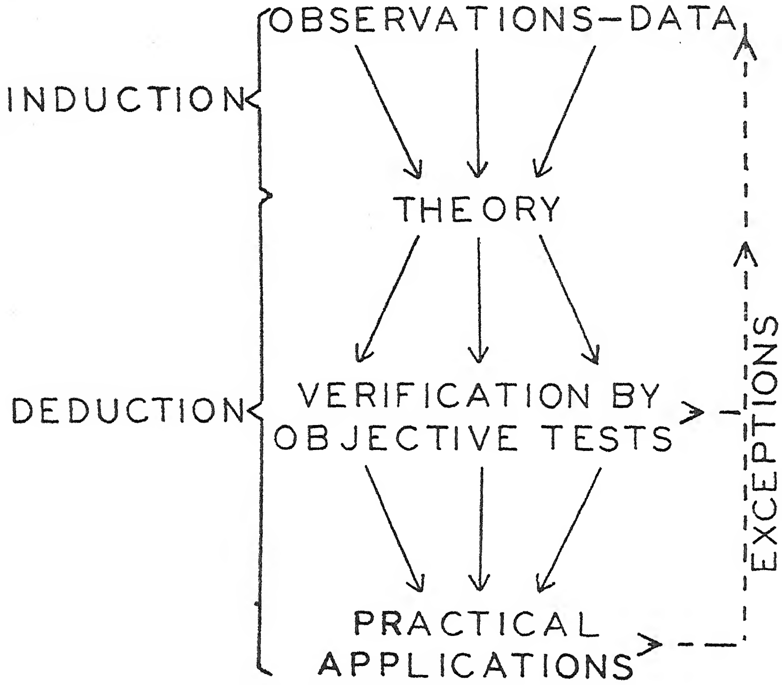

FIG. 1.—Analysis of logic of soil fertility research.

potassium. Statistical analysis will indicate whether or not the values determined are mathematically real. No detail of the calculation justifies the assumption that the results are significant in the sense that they are in any degree indicative of a specific response to potassium. If it should be shown that in a single instance a similar response could be produced by another treatment the effects of which are independent of potassium, it must be concluded that the interpretations implying a potassium deficiency have been incorrect. As the minor elements have been introduced into the program of work it has become increasingly evident that their effects are not independent of those of the common fertilizer materials. Results of experiments invariably measure the gross efficiency of fertilizer materials—not the effects of single elements nor of any particular function of these elements.

It should also be noted that all interpretations of research work are based upon assumptions or postulates which are not necessarily accurate. This generalization applies in particular to the rapid chemical tests for plant nutrients in the soil. The tests are standardized against interpretations of observations and as the latter are revised the standardizations will have to be altered accordingly. It is not improbable that the current difficulties found in developing these chemical tests are related more to the defects of basic concepts of soil fertility than to the limitations of chemical methods.

POTASSIUM "DEFICIENCY"

In the following discussion attempts will be made to illustrate only a few of the complexities of major soil problems which have been disclosed by experiments with the minor elements. For purposes of simplification, negative aspects will be emphasized. Results of specific objective tests, some of which have already been published, will be introduced to support the opinion that many of the classical ideas regarding the major principles of soil fertility are subject to question and that the functions of some of the minor elements are so intimately associated with major soil problems as to merit consideration in every detail of organization and interpretation of research work.

In the foregoing discussion reference was made to a suppositive experiment with potassium. An example has been published (3)[3] in which the data obtained on one field can be compared with that of another experiment (16) on adjacent plats. To facilitate the discussion the pertinent results are restated in Table 1. The basal fertilizer was identical in each experiment, except that in the work with copper and manganese a soluble source of magnesium was applied to all plats.

TABLE 1.—*Relative effects of potash, manganese, and copper on yield of cotton where "rust" is prevalent.*

Potash plats		Copper-manganese plats	
Treatment per acre	Lbs. seed cotton per acre	Treatment per acre	Lbs. seed cotton per acre
Fertilizer alone	965	Fertilizer alone*	1,320
Fertilizer with:		Fertilizer with:	
25 lbs. potash (sulfate)	1,205	5 lbs. manganese sulfate	2,040
25 lbs. potash (muriate)	1,385	10 lbs. copper sulfate	1,960
25 lbs. potash (kainit)	1,550		
25 lbs. potash (sulfate of potash-magnesia)	1,545		

*This formula was identical with that used on the potash plats except that it contained soluble magnesia.

Evidence of a response to magnesium was found in the potash experiment, but unfortunately magnesium was not supplied with the most efficient source of potassium. By any comparison of actual or

[3]Figures in parenthesis refer to "Literature Cited", p. 894.

calculated yields, however, it is obvious that small amounts of either copper or manganese produced results at least as satisfactory as were obtained with the additional amounts of potash fertilizers. The sponsors of the work with potash, having access to the results with copper or manganese, concluded that "factors other than potash may be involved". Those responsible for the work with copper and manganese have no positive opinion regarding the most practical remedy for cotton "rust". The general significance of these results lies in the fact that the potash experiment quite definitely "proved" the fact of a potassium deficiency. *The possibility of error was evident only after an experiment was designed to test an extremely doubtful theory.* If the minor element effect had been determined first the error might have been reversed.

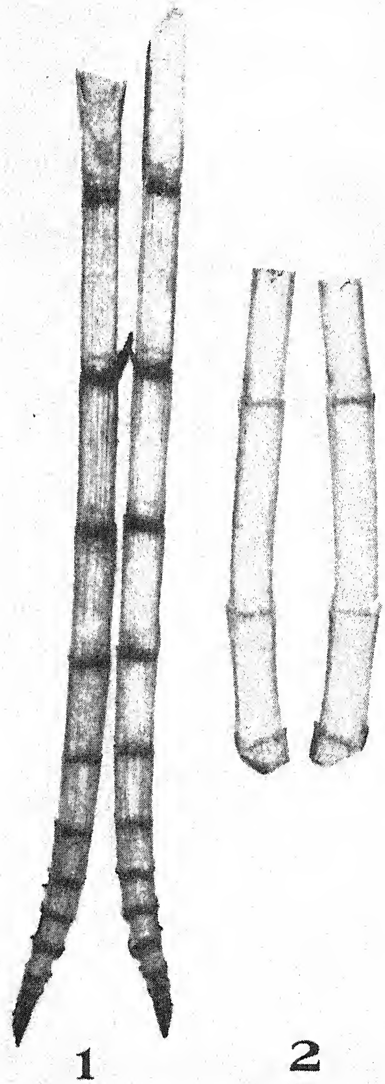

FIG. 2.—Accumulation of manganese (1) in nodes of corn stalk; (2) normal corn stalk.

No extensive discussion of this phase of the soil fertility problem can be undertaken. Hoffer (1) has shown that a condition remedied by potash fertilizers, which he identifies as a deficiency, is characterized by an accumulation of iron in the nodes of corn plants. Evidence from Ohio (8) indicates that the symptom is not infallible in either the positive or negative sense. Numerous semiquantitative tests have suggested the probability that symptoms generally considered indicative of potassium deficiency are in fact caused by an excessive intake of iron or manganese by the plants. Copper (12) or potassium salts (1) will control the former and apparently manganese is also effective. The visible symptoms caused by an excess of manganese (Fig.

2) are similar to those caused by iron, but it is probable that any soluble salt will, by a base exchange reaction (6), greatly increase the injury from manganese. (It may be stated at this time that experiments now in progress have demonstrated that manganese cannot be made insoluble in some soils by liming even at rates to produce pH values of 7.5.)

Other evidence dealing with supposedly specific effects of potassium will be introduced under the discussion of the phosphorus problem.

PHOSPHORUS DEFICIENCY

For the sake of simplification all general references to the experimental work with phosphorus will imply that ordinary superphosphate is the source of the element. Considering all of the components of this material there are on record at least ten major physiological effects that can be attributed to superphosphate, only one of which is the direct physiological function of phosphorus.

The complexity of the phosphate problem can be conveniently illustrated by the results of a reconnaisance experiment on a muck soil. Past experience had indicated that a standard complete fertilizer was ineffective, but the normal interpretation of no nutrient deficiency was complicated by evidence that phosphates alone were injurious (1, 9). In earlier interpretations it had been inferred that this denoted an unfavorable nutrient ratio, but, since the injury was usually associated with an apparently excessive intake of iron, an opinion was reached that the problem involved some features of an oxidation-reduction equilibrium (16).

Direct experimental support for this opinion appeared to be unobtainable so it was assumed from fragmentary evidence that the sequence of reactions was as follows: An injury was caused by iron which was brought into solution by reduction promoted by microbial activity which was in turn stimulated by the phosphate. This implied that the decrease in yield with the phosphate was evidence of a deficiency of phosphorus in the soil for the higher as well as the lower orders of plants. If, therefore, the reductive influence could be controlled, phosphorus should be beneficial. Copper sulfate was applied to soils in the field on the further assumption that it would act favorably as a catalyst of oxidation.

The only data indicative of an actual response to phosphorus comes from an experimental field[4] where copper sulfate was added to one-half of each plat of an experiment originally designed to test the efficiency of various sources of phosphorus. Unfortunately *nitrogen* was included in some of the treatments making it impossible to state that the results were due solely to other materials.

There is an element of inconsistency in the foregoing reference to nitrogen. Actually, the material used was nitrate of soda. The possible significance of this distinction will be discussed later, but for convenience, reference will be made indiscriminately to the element although it is recognized that the material is perhaps the more significant designation.

[4]Unpublished results furnished by W. H. Rankin.

In Fig. 3 it is shown that the plat receiving nitrogen and phosphorus produced less yield than did the unfertilized soil but that either copper or potassium served as a remedy for this adverse condition. A more striking effect of copper was found with the complete fertilizer. Since copper did not produce a comparable increase in yield without fertilizer, it is evident that *there was a need for standard fertilizers on this soil which had not been demonstrated before the copper was added.* It is still impossible to state what part of the composite effect was caused by the individual ingredients although the theory on which the application of copper was based implies a serious deficiency of phosphorus and no specific deficiency of copper as a plant nutrient.

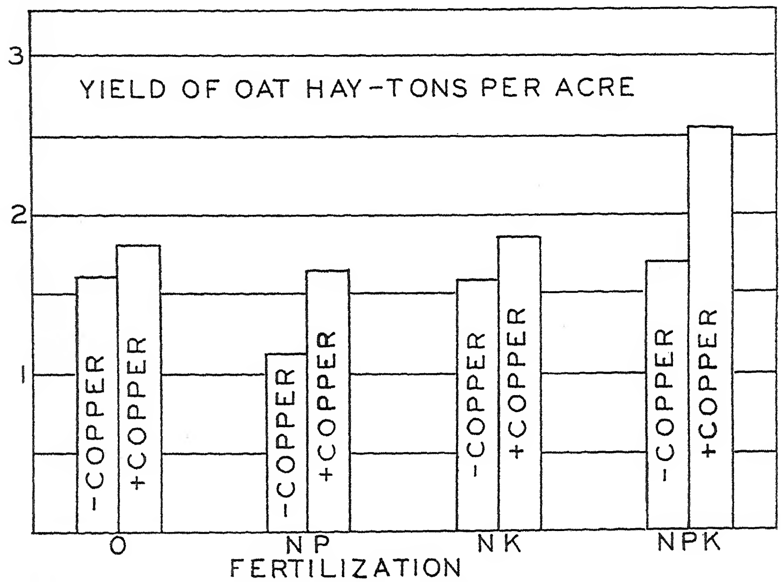

FIG. 3.—Influence of fertilizer and copper sulfate on yield of oats on a muck soil.

Recent observations indicating a widespread need for boron seem also to have a bearing on the phosphate problem. Evidence that calcium compounds increase the apparent deficiency of boron suggests that the efficiency of superphosphate may be seriously impaired where the boron supply of the soil is low. Under such conditions, orthodox methods of experimentation would lead to erroneous conclusions.

It is also evident, in view of the known effect of calcium sulfate as a solvent for both potassium and magnesium in the soil (11), that the results obtained with phosphate may be governed in part by this function. Any fertilizer mixture containing superphosphate which may be designed for use on soils at the threshold of either potassium or magnesium deficiency may therefore give false values attributable to phosphorus. Conversely, the deficiencies of potassium and magnesium evidenced where high analysis fertilizers have been used may be indicative of limited solvent action rather than to lesser amounts

of these elements in the fertilizer. This detail of the fertilizer problem leads to a suggestion that an apparent superiority of superphosphate over other sources of phosphorus may be indicative of a soil-depleting effect with the former material.

NITROGEN

A distinction between the use of the term nitrogen and nitrate of soda has already been drawn. In addition to the recognized effects upon soil reaction, the possibility of the intervention of oxidation-reduction phenomena must be considered. So, for example, the results of experiments with oats on the muck soils do not indicate a need for nitrogen any more than for oxidation. The relative efficiency of ammonium and nitrate nitrogen may in many instances depend upon the latter factor. Since it appears that copper will promote oxidation, it would be expected that this element might under some conditions modify the efficiency of ammonium nitrogen, or, equating other effects to that of copper, it might be expected that the exclusive use of ammonium nitrogen would increase an apparent rather than a real requirement for potassium.

As regards the functions of organic forms of nitrogen, evidence of a fallacy in the conclusion that these are valuable because of their slow availability has already been published (5). From the information available it appears that the organic ammoniates in general derive their efficiency in an appreciable degree from an effect common to all forms of readily decomposable organic matter and that differences in efficiency of the various sources of organic nitrogen may be attributable in part to functions of the minor element impurities.

SOIL ACIDITY—LIME

Extensive areas of soil in the southeastern states have not responded to liming as have soils in other parts of the country. Results of field experiments have proved that liberal liming has not been beneficial and this in turn has led to a conclusion that the soils must be kept distinctly acid. For some time it has been known that liming will promote a deficiency of manganese (10) on many of these soils and more recently it has been found that boron will apparently correct some of the adverse effects of liming (14, 4). The further observation that manganese deficiency symptoms have been nearly eliminated by an application of borax (15), together with an unrecorded observation that heavy fertilization increases the severity of manganese deficiency, suggest a wide field for further research.

It is obvious, however, that few of the conclusions derived from liming experiments are dependable where deficiencies of boron or manganese are potential limiting factors in crop production. In this, as in other similar problems, the burden of proof rests with the experimental work to show that these factors are not involved. It is not improbable that in the avoidance of certain minor element deficiencies, many soils have been maintained at pH values so low as to impair their productiveness.

The influence of calcitic and dolomitic limestones relative to magnesium deficiency is already recognized and experimental procedures have generally been revised to correct some of the errors of prior work.

MOISTURE RELATIONSHIPS

A chance observation (15) supported by a number of unrecorded experiences indicates that an abnormal susceptibility of plants to wilting may be controlled by applications of borax to the soil. The conditions have been such as to make it seem improbable that the results were due to appreciable differences in the supply of available moisture. Further research will be necessary before extensive comment can be justified relative to this feature of the work.

ORGANIC MATTER

The beneficial functions of organic matter in soils have been ascribed to improvement in physical condition, better moisture retention, and promotion of microbial activity. The latter effect is more or less vaguely associated with increasing the availability of plant nutrients. Any or all of these functions may be significant, but it is of more than casual interest that in Florida manure has corrected a manganese deficiency (7), in Finland manure has produced a response similar to that of boron (2), and that in North Carolina manure has corrected a condition indicative of a potassium deficiency (9) which was later found to be controllable by copper sulfate. In a direct comparison by means of pot culture studies (15) a very light application of a mixture of copper and manganese has produced results with tomatoes comparable to those obtained with 5 tons of manure.

Before this information had been obtained, comprehensive systems of farming had been developed with the application of animal manure as an essential part of the program. The possibility that a considerable part of the value of the manure is derived from some minor ingredient has not been seriously considered—except where the use of manure has become impractical.

GENERAL DISCUSSION

The foregoing evidence may seem insufficient to justify serious consideration. The philosophical principle, however, provides that although a mass of data may support an opinion, a single observation can refute it. Great emphasis has been placed upon *facts* and *fundamental data* in research. Facts and data are matters of record and are valuable only as they can be projected by means of theoretical interpretations into untested usages.

Interpretations are fallible. According to a critical analysis of the basal assumptions regarding soil fertility, it seems that the only one which can be accepted without question is that plants require certain mineral elements for normal development independently of their environment. A few other details of the soil fertility problem may also be considered sufficiently well established to serve as a basis for further work.

To a great extent, however, current experimentation is based upon empiricisms and fallacies. It is often implied that if crude materials are used in sufficient amounts to supply the major nutrient elements, the minor element requirement will usually be satisfied. The only criterion of the adequacy of the supply of any element is plant response. In the absence of other identifying symptoms it would be impossible to state whether the limiting factors were the major or the minor components of any material. It is not improbable that the apparent requirements for major elements, as determined by ordinary field experiments, are in many cases distorted because, on the one hand, the yields are dependent upon some minor constituent of the fertilizer, while on the other, the requirements of the minor elements may be governed by some unidentified constituent of the fertilizer.

In view of all of these dependent factors it appears impossible to design an experiment that will produce accurate evidence of the amounts of nutrient elements necessary to produce a maximum crop in a soil even with the use of highly purified materials. Data purporting to indicate the "availability" of major or minor nutrient elements is also subject to misinterpretation. It would be interesting, for example, to determine whether or not the "availability" of the phosphorus in basic slag is in any degree dependent upon the influence of manganese or any other secondary constituent. A chemical method of analysis has been based on the assumption that the efficiency of the material is the measure of the availability of the phosphorus.

Acceptance of the foregoing opinions would appear to eliminate the field plat fertilizer experiment from a research program. This, however, is not a rational interpretation. It is only necessary to put the fertilizer experiment into its logical position as an objective test of a theory or as a detail of the practical application of research. If the latter is developed by deduction from approximately sound principles, it is a legitimate phase of a research program. When this perspective is introduced no difficulty will be experienced in converting the results of so-called fundamental research into practice. Comprehensive field experiments designed to determine empirical or independent values for fertilizer and lime requirements, and deficiencies or availabilities of nutrient elements are of questionable scientific or practical value even though every provision be made to insure technical accuracy.

As the complexities of soil fertility problems become more evident it may be well to consider whether or not the practical interpretations of research can be expressed in simple language so that farmers can be guided by printed directions. This was possible so long as land could be divided into that which would respond to normal fertilization and that which was unsuitable for cultivation. With the introduction of the minor elements as correctives of causes of unproductiveness, however, simple directions are no longer satisfactory. It may appear that where the limitation applies, soils are abnormal and limited in area. It is impossible, however, to identify the abnormal without defining the normal and a fair appraisal of recent developments points to the conclusion that the minor element problem involves in some

degree many soils, perhaps a majority, that have been hitherto considered normal.

The perspective introduced into soil fertility experimentation by research on the functions of the so-called minor elements directs attention to the defects in the interpretations of prior work. The scientific objective of modifying single independent variables is demonstrated to be unattainable in fact even though it has been made the basis of all fertilizer experiments. The interpretations of such experiments are therefore subject to unavoidable errors and practical applications derived from them are in some degree empirical. Recognition of this fundamental limitation constitutes the first step in increasing the efficiency of fertilizer usage. Further progress must depend upon accidental discovery or upon a more rational development of experimental procedure.

LITERATURE CITED

1. HOFFER, G. N. Testing corn stalks chemically to aid in determining their plant food needs. Purdue Univ. Agr. Exp. Sta. Bul. 298. 1926.
2. JAMALAINEN, E. A. Tutkimuksia lantun ruskotaudista. Valtion Maatalouskoetoiminnan julkaisuja, No. 72. (Pub. No. 72, Tikkurila Agr. Exp. Sta.). German abs., pp. 107–116. 1935.
3. MOORE, J. H., and RANKIN, W. H. Influence of "rust" on quality and yield of cotton and the relation of potash applications to control. N. C. Agr. Exp. Sta. Bul. 308. 1937.
4. NAFTEL, JAMES A. Soil liming investigations: V. The relation of boron deficiency to over liming injury. Jour. Amer. Soc. Agron., 29:761–771. 1937.
5. PILAND, J. R., and WILLIS, L. G. The stimulation of seedling plants by organic matter. Jour. Amer. Soc. Agron., 29:324–331. 1937.
6. SCHOLLENBERGER, C. J. Manganese as an active base in the soil. Soil Science, 25:357–358. 1928.
7. SKINNER, J. J., and RUPRECHT, R. W. Fertilizer experiments with truck crops. Fla. Agr. Exp. Sta. Bul. 218. 1930.
8. WELTON, F. A., MORRIS, V. H., and GERDOL, R. W. Corn stalks vs. field plots as a guide to the fertility requirements of the corn crop. Ohio Agr. Exp. Sta. Bul. 397. 1926.
9. WILLIAMS, C. B., MANN, H. B., and REA, J. L., Jr. Crop response to lime and fertilizer on muck soil. N. C. Agr. Exp. Sta. Bul. 292. 1934.
10. WILLIS, L. G. The effect of liming on the availability of manganese and iron. Jour. Amer. Soc. Agron., 24:716–726. 1932.
11. ———. The value of gypsum as a supplement to a concentrated fertilizer. N. C. Agr. Exp. Sta. Bul. 299. 1934.
12. ———, and PILAND, J. R. The influence of copper sulfate on iron absorption by corn plants. Soil Science, 37:79–83. 1934.
13. ———, ———. The function of copper in soils and its relation to the availability of iron and manganese. Jour. Agr. Res., 52:467–476. 1936.
14. ———, ———. A response of alfalfa to borax. Science, 86:179–180. 1937.
15. ———, ———. Some recent observations on the use of minor elements in North Carolina agriculture. Soil Science, 44:251–263. 1937.
16. ———. Evidences of the significance of oxidation-reduction equilibrium in soil fertility problems. Soil Sci. Soc. Amer. Proc., 1:291–297. 1937.

GROWTH AND YIELD IN WHEAT, OATS, FLAX, AND CORN AS RELATED TO ENVIRONMENT[1]

R. S. Dunham[2]

THE complex of factors included in environment importantly affects the growth and yield of plants. As Klages (4)[3] has suggested, the plotting of growth curves should add a datum to those observations commonly recorded by agronomists that would aid in the interpretation of varietal yields. There may be further uses for growth curves in determining the relative importance of certain environmental factors in one region as compared to another and even in estimating crop yields in an area of similar climatic conditions. The concensus of those who have attempted correlation of weather with yield and forecasts of crop production on the basis of meteorological data is that more refined studies are necessary in order to determine the possibility of forecasting yields in any given region.

The studies reported in this paper, made during 1934 to 1937, inclusive, include height measurements and phenological data for wheat, oats, flax, and corn in relation to temperature, precipitation, and moisture content of the soil under the growing crop.

REVIEW OF LITERATURE

The literature on the correlation of weather and crop yields with the view of forecasting such yields is much too voluminous to review in detail. Summary of this literature until 1929 has been published by the Food Research Institute, Stanford University (5), and an unpublished abstract of foreign investigations has been made available to the writer by the Bureau of Agricultural Economics, U. S. Dept. of Agriculture. A list of selected references on weather-crops compiled in the Department of Agronomy and Economics and Sociology, Kansas State College, Manhattan, Kansas, has been distributed in mimeograph form. Investigators are generally agreed that most data now available are inadequate for deductions concerning the influence of factors of environment on crop growth and yield. Although some forms of meteorological data are quite complete, phenological data are not. Furthermore, phenological observations at closer intervals than are commonly made appear desirable and perhaps essential. There is a need for basic knowledge concerning the influence of weather factors on plant growth.

Chilcott (3), in a summary of investigations covering 218 crop years at 16 stations on the northern Great Plains, found that, "Notwithstanding the fact that annual precipitation is a vital factor in determining crop yield, it is seldom if ever the dominant factor; but the limitation of crop yield is most frequently due to the operation of one or of several inhibiting factors other than shortage of rainfall."

Oldsberg and Griffing (5) call attention to two critical periods in the life of the

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[2]Agronomist and Assistant Professor. Critical reading of this paper by Dr. F. J. Alway, Chief of the Division of Soils, and Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, is gratefully acknowledged.

[3]Figures in parenthesis refer to "Literature Cited", p. 908.

wheat plant, *viz.* (a) germination and formation of the first leaf and (b) flowering. Since the size of the first leaf determines the size of the second leaf and the size of the second leaf influences the size of the third leaf, ultimately the size of the first leaf influences importantly the size of the plant. During the period from the formation of the first leaf to heading, the plant is far less sensitive to weather than during germination and emergence unless weather conditions are extreme. The amount of soil moisture in the period just prior to heading is very important.

Van deSande-Bakhuyzen and Alsberg (8) believe that, "the loss of water is the most important phenomenon occurring at the time of flowering. It is the initial phase of death of the annual." The length of survival (5) after flowering is an important factor determining yields. Any environment conducive to drying hastens death and consequently reduces yields.

Pope (6) found that, "total height . . . indicates fairly well the growth stage of a plant. As a measure of growth it is, however, subject to certain sources of error. . . . Each leaf has its own grand period of growth and therefore the grand period of growth, as indicated by the curve of the height of the plant, varies with the growing activity of the leaf extending the greatest distance distally from the crown. . . . This error is greatly reduced by averaging the measurements of a plant population which varies in number and stage of growing leaves."

MATERIALS AND EXPERIMENTAL PROCEDURE

The surface soil of the plats used in this investigation is black silty clay loam underlaid with a calcareous lacustral clay. The texture of the soil and subsoil is indicated by the moisture equivalents reported in Table 1, which were determined by the Division of Soils of the University of Minnesota.

TABLE 1.—*Moisture equivalents of samples of soil from different plats.*

Depth, inches	Moisture equivalents						Average wilting coefficient*
	Plat 1	Plat 2	Plat 3	Plat 4	Plat 5	Average	
3– 6....	24.9	24.7	24.9	24.5	25.1	24.8	13.5
9–12....	23.2	22.1	20.3	22.6	21.1	21.9	11.9
21–24....	25.6	25.6	23.4	20.4	25.2	24.0	13.0
33–36....	27.8	28.1	28.5	24.5	28.3	27.4	14.9

*Wilting coefficient-moisture equivalent multiplied by $\frac{1}{1.84}$. (Briggs, L. J., and Schantz, H. L. Wilting coefficient for different plants and its indirect determination. Bur. of Plant Ind., U. S. D. A. Bul. 230. 1912.)

The soil of these plats does not respond to applications of nitrogen or potassium fertilizers. Liberal amounts of treble superphosphate were applied broadcast in 1934 and placed with the seed in 1937 so it may be assumed that growth and yield were not limited by a deficiency in soil nutrients. The plats were all kept in bare fallow the year before the investigations began and have been cropped subsequently, as shown in Table 2.

Varieties used were Thatcher wheat, Anthony oats, Redwing flax in 1934 and 1935 and Bison in 1936 and 1937, Northwestern Dent (Crookston) corn, and the common biennial white sweet clover.

The purpose of the study was to compare the growth curves and yields of wheat, oats, flax, and corn over a period of years in relation to environmental conditions. A fortieth acre plat of each crop was sown and 10 plants selected from each plat. Soon after emergence these plants were tagged and measuring bases placed be-

TABLE 2.—*Crop sequence on plats.*

Plat No.	1934	1935	1936	1937
1	Wheat	Sweet clover alone	Sweet clover	Wheat
2	Oats	Wheat	Corn	Oats
3	Barley	Oats	Corn	Flax
4	Flax	Flax	Flax, sweet clover	Sweet clover
5	Wheat, sweet clover	Sweet clover	Flax	Corn
6	Sweet clover sown alone	Sweet clover	Oats	Corn
7	Corn	Corn	Wheat	Corn

side each. The bases consisted of a piece of heavy wire about a foot long with a 1-inch piece at the top bent at right angles. The wire was then inserted in the ground until the bent over top lay horizontal on the surface. During the season these measuring bases were covered several times with soil that had washed or blown over them, but they were easily uncovered. They provided a base from which all measurements were made and which eliminated errors that would have followed the use of the ground surface for this purpose.

Heights in inches were taken at approximately weekly intervals from the measuring base to the tip of the tallest leaf or the tip of the inflorescence, whichever was taller. In averaging the height of 10 plants, the error due to measuring the same leaf which varies in its growth activity was reduced. (6). Furthermore, the method of measuring length-growth removed the obvious objections to determining mass whereby samples would of necessity be removed from the field and new samples required for each determination.

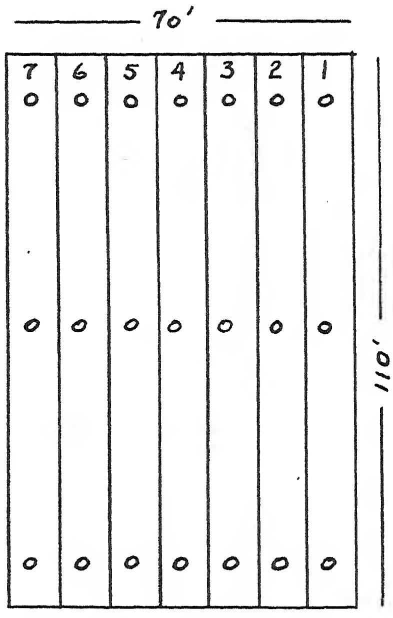

FIG. 1.—Arrangement and dimensions of plats showing approximate location of borings for soil moisture samples.

Soil moisture samples were taken at 3- to 6-inch, 9- to 12-inch, 21- to 24-inch, and 33- to 36-inch depths at intervals of approximately 2 weeks. Borings were made at three locations on each plat (Fig. 1), the soil thoroughly mixed, and a composite sample used for the determination. The percentage of total moisture was found by drying the samples in an electric oven at 100° C.

For the first three years, 2 square yards were cut from each plat at time of each height measurement, the plant material dried to a water-free basis, and weighed. However, the lack of uniformity in stand and growth made comparisons of one cutting with another of doubtful value, so this procedure was discontinued.

Two square yards per plat of wheat, oats, and flax were cut for yield but weight of 1,000 seeds was based on seeds from the 10 plants on which observations were made. In corn, a measured portion of the row was harvested. The area used was too small for reliable comparisons of the grain so only yields of stover are reported.

RESULTS

In Fig. 2, growth curves for wheat, oats, flax, and corn for each of the four seasons are shown. The curves connect points which represent the average height of the 10 individuals measured at approximately weekly intervals except where the data from an individual have been discarded for reasons discussed below.

The use of several individuals for measurement has several advantages over mass sampling, as follows: (a) A comparison of individuals may be made in growth, yield, and disease. A factor obscured in measurements of mass samples may easily be disclosed in the observation of individuals. Thus, wheat plant No. 4 in 1934 bore 39 kernels per spike as compared to 28.9, the average for the other nine individuals. Its kernels weighed 34.5 grams per 1,000 as compared to the average of 26.3 grams. It carried 10% stem rust as compared to a maximum of 2% for the other individuals. After heading, this individual proved to be a rogue and all data pertaining to it were discarded. (b) Individuals accidentally injured or killed are easily detected and eliminated from consideration. In 1936, oats plant No. 8 was injured. In four successive measurements it fell short of the average height by 2.6 inches, 4.8 inches, 6.2 inches, and 10.6 inches. (c) Variation due to individual differences may be measured and used for the determination of this error. (d) Individuals may be selected in areas of full stand and free from weeds, ant hills, animal droppings, etc.

In Table 3, precipitation data for the four years are presented. A comparison of the cumulative precipitation for these years with the average for 36 years shows that (a) the precipitation is average for 1934 if the excess moisture from the preceding season is disregarded and since this excess did not appear in soil moisture samples taken in the early spring (Table 4), it may be disregarded; (b) the precipitation for 1935 is also approximately average; (c) the precipitation for 1936 is below average all season; and (d) the precipitation for 1937 is generally above average.

The moisture stored in the soil from the end of one crop year till the beginning of the next is a factor to be considered. A column in Table 3 reports "Precipitation since harvest last year". Since the land on which the plats were laid out was fallowed in 1933, the rainfall of the 1933 crop season is added to the precipitation of fall and winter in this year. No measurements of evaporation or run-off were made, but the soil on each plat was sampled at time of crop emergence and the percentage of water found. The percentages of total water in the soil under each of the four crops and average wilting coefficients at depths of 3 to 6 inches, 9 to 12 inches, 21 to 24 inches, and 33 to 36 inches for 1934–37 are given in Table 4 and presented graphically in Fig. 3.

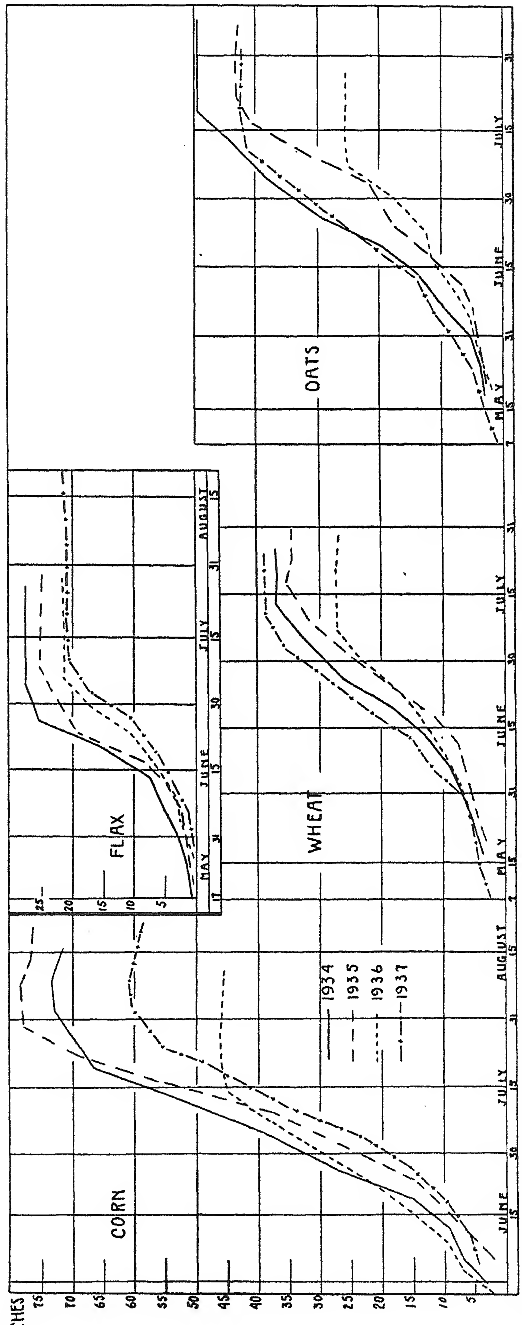

FIG. 2.—Growth curves for corn, flax, wheat, and oats during the seasons 1934–37. The ordinate represents height in inches and the abscissa, approximate date of measuring.

TABLE 3.—*Precipitation preceding and during the growing seasons 1934–37 and 36-year averages.*

Year and crop	Precipitation since harvest last year, inches		Cumulative precipitation during growing season															
1934			May 17	May 24	May 31	June 6	June 13	June 20	June 26	July 5	July 13	July 19	July 25	Aug. 1	Aug. 8	Aug. 16		
Wheat	May 1, 1933–May 7, 1934,	17.64	17.7	17.8	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	—	—	—		
Oats	May 1, 1933–May 7, 1934,	17.64	17.7	17.8	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	26.5	26.7	—		
Flax	May 1, 1933–May 7, 1934,	17.64	17.7	17.8	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	—	—	—		
Corn	May 1, 1933–May 22, 1934,	17.80	—	—	19.3	20.4	21.4	22.2	24.2	24.8	26.5	26.5	26.5	26.5	26.7	27.2		
36-yr. av.	Sept. 1–May 17,	9.6	9.6	—	11.1*	—	—	—	14.4†		—	—	—	17.3‡	—	18.6§		
1935			May 20	May 27	June 6	June 11	June 17	June 24	July 2	July 9	July 16	July 22	July 29	Aug. 7	Aug. 13	Aug. 20		
Wheat	Aug. 8, 1934–May 4, 1935,	9.21	10.1	10.4	11.6	11.7	12.5	12.7	13.3	15.3	16.7	16.9	17.8	—	—	—		
Oats	Aug. 1, 1934–May 4, 1935,	9.27	10.2	10.5	11.7	11.8	12.6	12.8	13.4	15.4	16.8	17.0	17.9	18.3	—	—		
Flax	Aug. 8, 1934–May 14, 1935,	10.13	10.1	10.4	11.6	11.7	12.5	12.7	13.3	15.3	16.7	16.9	17.8	—	—	—		
Corn	Aug. 30, 1934–May 17, 1935,	9.22	—	—	10.7	10.8	11.5	11.8	12.4	14.4	15.8	15.9	16.9	17.3	17.6	19.9		
36-yr. av.	Sept. 1–May 20,	9.8	9.8	—	11.3*	—	—	—	14.6†	—	—	—	17.5‡		18.8§			
1936			May 19	May 26	June 3	June 9	June 16	June 23	June 30	July 7	July 14	July 21	July 28	Aug. 11				
Wheat	Aug. 7, 1935–May 6, 1936,	9.09	9.1	10.0	10.0	10.8	10.9	10.9	11.7	11.8	11.9	12.3	12.3	—	—	—		
Oats	Aug. 7, 1935–May 13, 1936,	9.09	9.1	10.0	10.0	10.8	10.9	10.9	11.7	11.8	11.9	12.3	12.3	—	—	—		
Flax	Aug. 7, 1935–May 13, 1936,	9.09	—	10.0	10.0	10.8	10.9	10.9	11.7	11.8	11.9	12.3	12.3	—	—	—		
Corn	Aug. 28, 1935–May 13, 1936,	5.91	—	—	6.8	7.6	7.7	7.8	8.6	8.7	8.7	9.1	9.1	9.2	—	—		
36-yr. av.	Sept. 1–May 19,	9.7	9.7	—	11.2*	—	—	—	14.5†	—	—	—	17.4‡			18.7§		
1937			May 7	May 15	May 23	May 29	June 5	June 12	June 19	June 26	July 3	July 10	July 20	July 24	Aug. 2	Aug. 7	Aug. 14	Aug. 21
Wheat	July 28, 1936–April 17, 1937,	6.01	9.3	9.6	10.8	11.0	13.9	14.3	14.5	14.8	14.9	15.1	17.8	18.6	20.2	—	—	—
Oats	July 28, 1936–April 19, 1937,	6.01	9.3	9.6	10.8	11.0	13.9	14.3	14.5	14.8	14.9	15.1	17.8	18.6	20.2	20.2	—	—
Flax	July 28, 1936–May 11, 1937,	9.51	—	—	—	11.0	13.9	14.3	14.5	14.8	14.9	15.1	17.8	18.6	20.2	20.2	20.5	20.6
Corn	Aug. 11, 1936–May 14, 1937,	9.44	—	—	—	—	13.6	14.0	14.2	14.6	14.6	14.8	17.5	18.3	19.9	19.9	20.2	20.3
36-yr. av.	Sept. 1–May 7,	9.0	9.0	—	—	—	11.1*	—	—	14.4†		—	—	17.3‡		—	18.6§	

*June 1.
†July 1.
‡Aug. 1.
§Aug. 15.

Although records of precipitation, run-off, evaporation, humidity, wind velocity, and temperature might disclose important relationships, it appears that the determination of soil moisture provides a single factor which represents a resultant of these elements of environment. Used over a considerable area in an effort to forecast crop yields, soil moisture data would tend to reduce the error intro-

TABLE 4.—*Percentages of total water in the soil under wheat, oats, flax, and corn and average wilting coefficients at depths of 3 to 6 inches, 9 to 12 inches, 21 to 24 inches, and 33 to 36 inches for each of the seasons 1934–37.*

Crop	Depth, inches	May 1934				June 1934		July 1934		Aug. 1934		Sept. 5, 1934
		8	16	23	31	8	21	6	20	1	18	
Wheat	3–6	25.1	25.8	24.1	23.3	29.3	22.0	21.9	19.7	12.0	—	—
	9–12	23.2	20.7	19.6	17.8	25.3	19.5	15.0	16.1	13.9	—	—
	21–24	20.7	21.0	20.3	19.7	23.7	18.7	16.6	15.7	16.4	—	—
	33–36	21.7	22.6	22.5	22.4	24.2	22.4	20.9	17.7	18.9	—	—
Oats	3–6	26.1	24.7	25.2	24.6	29.1	22.1	22.7	15.3	10.6	10.7	—
	9–12	21.1	18.9	18.1	18.3	20.5	17.5	13.5	13.1	7.5	8.6	—
	21–24	19.1	20.0	21.4	19.7	19.9	18.0	14.9	12.9	14.0	11.4	—
	33–36	20.2	22.0	20.6	21.1	22.1	21.0	22.1	18.8	16.9	13.1	—
Flax	3–6	25.8	26.0	25.2	23.7	29.5	20.2	19.0	15.0	9.7	—	—
	9–12	21.1	20.4	20.2	18.3	22.2	20.1	15.5	14.0	10.4	—	—
	21–24	17.9	16.4	15.9	17.6	21.1	17.1	16.6	9.5	8.7	—	—
	33–36	19.9	21.0	19.6	19.1	23.7	17.4	18.7	20.6	13.6	—	—
Corn	3–6	—	—	25.7	25.8	29.7	27.3	28.0	19.8	16.6	14.1	13.8
	9–12	—	—	19.9	19.1	22.3	22.8	21.7	18.8	9.9	8.0	9.3
	21–24	—	—	19.8	18.4	20.4	18.9	19.4	18.6	17.3	10.6	12.6
	33–36	—	—	21.4	22.1	21.8	21.7	21.6	21.3	21.6	17.9	15.2
		May 1935				June 1935		July 1935		Aug. 1935		
		10	24			6	20	5	19	2	17	
Wheat	3–6	24.8	24.5	—	—	26.5	22.9	26.1	19.5	17.2	—	—
	9–12	22.1	20.5	—	—	20.5	19.6	17.5	14.8	12.9	—	—
	21–24	20.2	20.7	—	—	20.5	18.5	17.1	18.2	13.8	—	—
	33–36	21.1	21.7	—	—	20.9	20.7	21.0	20.7	18.4	—	—
Oats	3–6	25.8	25.9	—	—	26.1	22.5	24.3	22.2	18.1	—	—
	9–12	19.7	19.7	—	—	19.8	19.3	15.1	13.9	8.5	—	—
	21–24	21.3	20.5	—	—	20.8	18.7	16.6	18.2	14.8	—	—
	33–36	22.1	22.5	—	—	21.3	21.2	19.6	22.1	20.2	—	—
Flax	3–6	—	26.4	—	—	28.1	24.9	28.1	21.3	18.7	23.6	—
	9–12	—	20.4	—	—	19.3	22.6	21.1	16.2	12.2	10.1	—
	21–24	—	18.4	—	—	17.0	16.7	20.6	16.9	13.2	11.5	—
	33–36	—	20.9	—	—	22.2	22.5	22.7	19.6	20.2	19.4	—
Corn	3–6	—	25.3	—	—	27.9	26.7	29.3	25.2	20.8	24.4	—
	9–12	—	18.1	—	—	19.5	20.2	20.6	18.2	14.1	11.9	—
	21–24	—	19.7	—	—	20.3	21.3	21.3	19.5	19.4	15.8	—
	33–36	—	20.1	—	—	21.0	21.5	21.7	21.8	21.4	19.5	—

TABLE 4.—*Concluded.*

Crop	Depth, inches	May 1936		June 1936		July 1936		Aug. 1936		
		16	29	12	26	10	24	2	14	31
Wheat	3–6	26.4	26.1	21.0	12.7	11.1	10.2	—	—	—
	9–12	19.5	22.0	15.3	9.5	9.0	6.6	—	—	—
	21–24	18.9	17.0	16.8	14.5	11.6	8.8	—	—	—
	33–36	21.1	19.8	18.2	15.4	14.2	9.6	—	—	—
Oats	3–6	25.8	26.3	23.1	26.7	13.2	9.0	—	—	—
	9–12	20.7	19.6	17.6	11.8	9.2	9.8	—	—	—
	21–24	18.5	19.7	18.7	16.6	13.3	9.6	—	—	—
	33–36	20.1	20.8	21.1	19.6	17.4	11.2	—	—	—
Flax	3–6	27.5	26.3	26.0	14.9	11.3	10.1	—	—	—
	9–12	20.0	18.2	19.2	11.8	8.4	8.3	—	—	—
	21–24	21.4	21.0	21.2	19.8	14.4	9.6	—	—	—
	33–36	20.9	21.5	21.2	21.6	19.5	14.0	—	—	—
Corn	3–6	27.7	27.8	24.0	25.3	16.9	27.0	—	—	—
	9–12	24.3	21.1	16.3	16.0	14.5	12.6	—	—	—
	21–24	23.2	22.8	21.1	23.6	20.3	17.9	—	—	—
	33–36	10.8	23.1	22.8	28.6	23.1	20.5	—	—	—
		May 1937		June 1937		July 1937				
		8	22	5	19	3	20			
Wheat	3–6	24.8	26.6	23.4	18.5	13.2	25.3	24.6	—	—
	9–12	21.4	24.4	22.3	17.4	14.8	21.4	17.6	—	—
	21–24	23.4	24.3	23.9	20.2	18.1	16.2	15.6	—	—
	33–36	22.1	22.4	23.3	24.8	18.0	14.1	13.7	—	—
Oats	3–6	26.6	26.6	26.8	21.9	13.3	24.0	23.7	—	—
	9–12	19.9	20.7	21.5	16.6	9.5	20.0	15.5	—	—
	21–24	22.4	23.7	22.9	18.7	18.6	13.0	14.0	—	—
	33–36	23.9	23.2	24.3	21.3	21.3	15.8	19.3	—	—
Flax	3–6	—	26.7	26.6	22.9	14.7	23.7	17.7	13.9	—
	9–12	—	19.2	20.0	18.0	14.4	18.7	13.5	11.6	—
	21–24	—	19.3	22.6	21.5	15.8	14.1	13.5	11.6	—
	33–36	—	20.9	23.0	23.9	21.1	17.2	16.7	13.4	—
Corn	3–6	—	27.1	26.5	25.3	23.5	26.1	22.1	18.9	15.7
	9–12	—	24.4	24.6	21.8	16.1	19.6	17.1	15.0	9.8
	21–24	—	23.1	23.5	20.7	20.3	21.5	19.7	17.7	12.3
	33–36	—	22.1	23.4	23.2	21.8	23.4	21.7	19.6	19.8

Average wilting coefficients

3–6	13.5
9–12	11.9
21–24	13.0
33–36	14.9

duced into crop condition estimates by local showers or local dry spots where no precipitation records are kept.

It is evident from Table 3, although difficult to explain, that there was no greater accumulation of water in the soil to a depth of 3 feet following fallow than in other years not preceded by fallow. In these years the precipitation from the harvest of the crop on each plat until

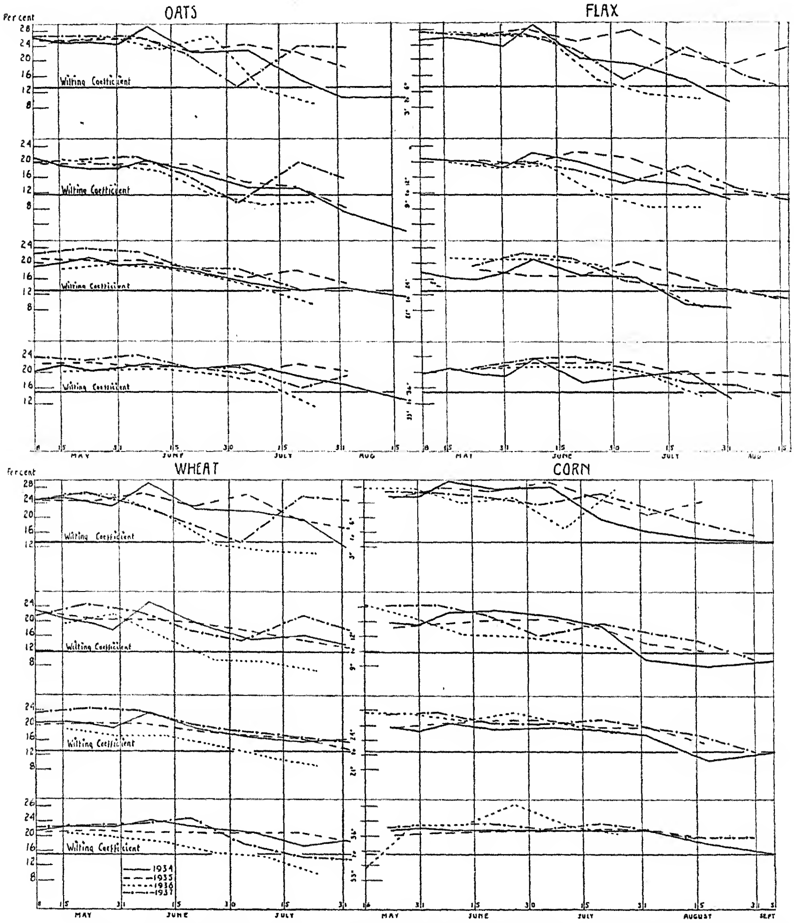

FIG. 3.—Percentages of total water in the soil under wheat, oats, flax, and corn and average wilting coefficients at depths of 3 to 6 inches, 9 to 12 inches, 21 to 24 inches, and 33 to 36 inches for 1934–37.

the planting of the new crop the following spring is given in the first column of Table 3. From this table and from Fig. 3, it may be seen that, particularly in the dry year of 1936, the grain crops have been able to reduce the subsoil moisture below the computed wilting coefficient. Growth curves in Fig. 2 show that wheat continued its growth after the soil moisture at all depths sampled had been so reduced, and in oats, flax, and corn growth continued after soil moisture

at one or two depths had been so reduced but not when it fell below the wilting coefficient at all depths.

In general, the available water supply in the soil from the middle to the latter part of the season was greater for corn than for any other crops studied (Fig. 3 and Table 3). During 1936, a season of low rainfall, the moisture content in the soil during the latter part of the season was low for wheat, oats, and flax but nearly as great in the corn plats as for other years.

It is evident that there is a trend toward exhaustion of soil water during the 1937 growing season even with more than average rainfall.

The mean temperatures for the intervals between measurements of the plants, the mean temperatures for each month during the growing season, and the average mean temperatures for 26 years are reported in Table 5. A comparison of monthly means for each year with the average shows (a) that 1934 was about average after a very warm May; that (b) 1935 was considerably colder than average in May and June, very much warmer in July, and slightly warmer in August; that (c) 1936 was warmer than average all season, July being the warmest month in 27 years of record; and that (d) 1937

TABLE 5.—*Mean temperatures for the intervals between dates given and averages for four summer months during growing seasons 1934–37 and 26-year average.*

1934	Temperature, °F	1935	Temperature, °F	1936	Temperature, °F	1937	Temperature, °F	26-year av.
May 17	62.8°	May 20	57.2°	May 19	63.7°	May 7	59.6°	
24	59.0°	27	56.2°	26	68.1°	15	53.2°	
31	72.8°					23	52.4°	
						29	65.2°	
Mean	63.0°		51.4°		61.4°		57.4°	54.6°
June 6	60.1°	June 6	53.4°	June 3	60.2°	June 5	62.5°	
13	70.3°	11	59.9°	9	64.3°	12	54.6°	
20	65.8°	17	62.3°	16	64.5°	19	67.4°	
26	69.3°	24	63.2°	23	68.9°	26	70.4°	
				30	66.8°			
Mean	64.4°		60.7°		64.4°		63.8°	64.2°
July 5	64.2°	July 2	74.1°	July 7	84.1°	July 3	66.5°	
13	69.7°	9	71.2°	14	87.1°	10	74.8°	
19	76.1°	16	72.3°	21	75.2°	20	68.3°	
25	71.3°	22	76.1°	28	74.3°	24	71.5°	
		29	74.4°					
Mean	69.8°		74.2°		78.7°		70.2°	69.7°
Aug. 1	71.1°	Aug. 7	71.7°	Aug. 11	73.0°	Aug. 2	69.4°	
8	71.3°	13	74.8°	13	72.0°	7	74.6°	
11	73.5°	20	65.1°			14	73.2°	
16	70.4°					21	70.4°	
25	56.7°							
Mean	66.6°		67.2°		69.4°		72.6°	66.7°

was about average except for a hot August and a warm May. August was the warmest on record.

In Table 6 are reported yields in bushels of grain and pounds of straw, weight per 1,000 seeds, and number of seeds per spike or boll.

TABLE 6.—*Yield of grain and straw, weight per 1,000 seeds, number of seeds per spike or boll, and height of plant.*

Crop	1934	1935	1936	1937	Average height*
Wheat:					
Yield in bushels	22.4	17.1	5.9	33.4	
Wt. per 1,000 kernels, grams	26.3	27.4	20.4	20.0	
No. kernels per spike	28.9	26.7	24.5	20.0	
Wt. of straw and grain, lbs.	3,628	2,737	1,264	7,020	
Wt. of grain, lbs.	1,578	1,026	354	2,004	
Wt. of straw, lbs.	2,050	1,711	910	5,016	
Ht. in inches	37.4	34.3	27.5	36.7	30
Oats:					
Yield in bushels	62.5	30.5	—	67.1	
Wt. per 1,000 kernels, grams	25.3	24.7	9.2	25.3	
Wt. of straw and grain, lbs.	4,069	3,139	1,197	5,600	
Wt. of grain, lbs.	2,000	976	—	2,147	
Wt. of straw, lbs.	2,069	2,163	1,197	3,453	
Ht. in inches	50.6	43.1	25.6	42.5	41
Flax:					
Yield in bushels	12.7	10.2	3.8	11.0	
Wt. per 1,000 seeds, grams	3.9	5.2	3.3	5.9	
No. seeds per boll	7.4	6.6	5.0	6.3	
Wt. of grain and straw, lbs.	1,776	1,694	699	3,180	
Wt. of grain, lbs.	711	571	212	616	
Wt. of straw, lbs.	1,065	1,123	487	2,564	
Ht. in inches	27.8	25.0	21.5	21.9	20
Corn:					
Yield of forage in lbs.	7,300	6,963	2,482	3,762	
Ht. in inches	73.1	78.7	46.1	61.0	61

*Nine-year average for wheat, flax, and corn, 1929–1937; 13-year average for oats, 1925–1937.

The four years' data reported in Table 6 represent too short a period to make advisable any statistical treatment or definite conclusions. Some apparent tendencies, however, may be pointed out. The weight of straw seems associated rather directly with yield in wheat and to a less extent in oats and flax. Weight per 1,000 seeds is associated rather directly with yield in oats and to a less extent in flax. The association is much less apparent in wheat. The number of seeds per boll is associated directly with yield in flax, but the association between number of kernels per spike and yield of wheat is not so apparent.

If the total precipitation from the harvest of one season to the harvest of the next is considered (Table 3), there is an apparent association between yield and precipitation for wheat, oats, and flax in 1935 and 1936, but not in 1937 and 1934 unless the precipitation during the preceding year of fallow is disregarded. These associations may be more apparent than real, however.

Since 1936 was a year of extreme heat and drought, its significance in any correlation study is not important even though definite. The heat of July 1936 blasted oats blossoms before they were fertilized so that grain yields were impossible and it probably injured wheat.

The apparent association between yield and precipitation in 1935 may be accidental since the temperatures of July were high and may have reduced the yield. This is borne out by the fact that the total moisture in 1935 did not fall below the wilting coefficient in the July samples and as an average of all depths there was as much available water in the soil for all crops on corresponding dates in July 1935 as in 1934 or 1937 with the one exception of July 20, 1937, for wheat. The lack of association between yield of flax and precipitation may also be explained by the injurious effect of a hot August that retarded normal growth and delayed ripening.

In corn there appears to be no association of yield of forage with rainfall and not uniformly with height. The tall growth in 1935 may be explained by the combination of high temperatures and adequate moisture, while the shorter growth in 1937 with more than average moisture may have been due to temperatures lower than optimum; the high temperatures of August coming too late for an early variety such as Northwestern Dent (Crookston strain).

TABLE 7.—*Dates of heading or flowering and ripening and notes on disease of wheat, oats, flax, and corn 1934–1937.*

Crop	Year	Date*	Date ripe	Disease notes
Wheat	1934	June 26–July 5	Aug. 5	2% stem rust on 1 plant; others trace or none.
Oats		—	Aug. 16	25% stem rust on 3 lodged plants; others none.
Flax		July 5	Aug. 8	Trace stem rust on 1 plant; others none.
Corn		Aug. 8	Aug. 30	
Wheat	1935	July 2–July 9	Aug. 7	2% stem rust on 2 plants; others trace or none; moderate leaf rust.
Oats		July 16	Aug. 7	10% stem rust on 1 plant; 5% on 2 plants; others trace or 0; heavy crown rust on all plants.
Flax		July 9	Aug. 12	
Corn		July 16	Aug. 28	
Wheat	1936	June 23–June 30	July 28	
Oats		July 11	July 28	
Flax		June 30–July 7	July 28	
Corn		July 14	Aug. 4	Dried up.
Wheat	1937	July 3	Aug. 2	No stem rust; light leaf rust; 1 plant affected by root-rot.
Oats		July 10	Aug. 7	15% stem rust on 1 plant; light crown rust on all.
Flax		July 3–July 10	Aug. 21	Trace of stem rust on 6 plants; others none.
Corn		July 24–Aug. 2	Aug. 31	

*Date of heading in wheat and oats; full bloom in flax; tasseling in corn.

In Table 7 are reported notes on diseases affecting the crops. Thatcher and Anthony are resistant to stem rust (*Puccinia graminis tritici* and *avenae*). The infection reported included pustules of the resistant type only. Although Thatcher is not resistant to leaf rust (*Puccinia triticina*) and Anthony is not resistant to crown rust (*Puccinia coronata avenae*), comparison of number of kernels produced and weight per 1,000 on individual plants with and without infection indicated no injury from the disease in the amounts found in these trials. Flax wilt (*Fusarium lini*) did not appear in any of the plats and only a trace of stem rust (*Melampsora lini*) was ever present. More complete control of the rust might have been accomplished by dusting with colloidal sulfur, but it is believed that the disease factor in these investigations was of negligible importance. There was no insect or mechanical injury so that differences in growth and yield may be attributed at least importantly to meteorological factors.

Phenological data reported in Table 7 are of interest when considered in relation to the growth curves shown in Fig. 2.

SUMMARY

1. Growth curves and data on yields of wheat, oats, flax, and corn, together with weight per 1,000 kernels of wheat, oats, and flax during a period of four years, 1934–1937, are presented.

2. Temperature and precipitation data and graphs of soil moisture in the plats on which these crops were grown are presented.

3. Methods employed in this study are described in detail.

4. The period of investigation is too short to warrant a statistical analysis or definite conclusions.

5. Certain tendencies may be observed as follows: (a) In wheat there is a positive and fairly consistent association between weight of straw and yield of grain when the four years' data are considered. The association is much less apparent in oats and flax. (b) Weight per 1,000 kernels is associated rather directly with yield of oats grain and to a less extent in flax. The association is much less apparent in wheat. (c) The number of seeds per boll is associated directly with yield of flax seed, but the association between number of kernels per spike and yield of wheat grain is not apparent. (d) Associations of yield with precipitation may be more apparent than real since the temperature factor is important. (e) In corn there appears to be no association of yield of forage with rainfall and not uniformly with height.

6. Measurement of several individual plants present some important advantages over mass samples, as follows: (a) Comparison of individuals in growth, yield, and disease can be made. (b) Individuals accidentally injured or killed are easily detected and eliminated from consideration. (c) Variation due to individual differences may be measured and used for determination of this error. (d) Individuals may be selected in areas of full stand and free from weeds, ant hills, animal droppings, etc. (e) The same samples may be used for each determination.

7. The available soil moisture offers a single factor which represents a resultant of various elements of environment.

8. In 1936, growth continued in wheat after soil moisture at all depths sampled had been reduced below the computed wilting coefficient.

9. In oats, flax, and corn growth continued after soil moisture at one or two depths had been so reduced.

LITERATURE CITED

1. BARNARD, M. M. An examination of the sampling observation on wheat of the crop-weather scheme. Jour. Agr. Sci., 26:456–487. 1936.
2. BARNES, S., and HOPKINS, E. S. Soil moisture and crop production. Dom. Dept. Agr. Bul. 130 (new series). 1930.
3. CHILCOTT, E. C. The relations between crop yields and precipitation in the Great Plains area. Misc. Cir. No. 81. Bur. Plant Ind. U. S. D. A. 1927.
4. KLAGES, K. H. The value and appreciation of growth curves to field plat experiments. Jour. Amer. Soc. Agron., 25:453–464. 1933.
5. OLDSBERG, C. L. and GUFFING, E. F. Methods of forecasting yields from the weather: Wheat studies. Food Res. Inst., 5 (Sept.). 1929.
6. POPE, MERRITT N. The growth curve in barley. Jour. Agr. Res., 44:323–341. 1932.
7. YATES, F. Crop estimating and forecasting. Jour. Mini. Agr., 43:156–162. 1936.
8. VAN DE SANDE-BAKHUYZEN, H. L., and ALSBERG, CARL L. The growth curve in annual plants. Phys. Rev., 7:151–187. 1927.

ZONAL DISTRIBUTION OF NITRATES AND ITS EFFECT ON NODULATION OF SOYBEANS[1]

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Though nitrates and ammonium salts as fertilizers have been credited with inhibitive effects on nodulation by legumes, their effects on the production and distribution of nodules as a consequence of their varied local concentration in the growing medium have not been adequately investigated.

Strowd (3)[3] and Wilson (4) concluded from their studies with soybean plants, by dividing their roots in such a way that a number of them were grown in nitrate-bearing and a number of them of the same plant in nitrate-free part of the same medium, that the peculiar injurious effects by nitrates on nodulation are entirely local in character.

Possibly the nodulation effects by different concentrations of nitrates would be different if the same root were growing through both nitrate-free and nitrate-bearing zones in the medium. Since by this method nitrates absorbed in the distal part of the root must pass through all points lying towards the stem, it would be possible thereby to determine whether the effects are distinctly local or of a more general nature. This arrangement of growing the same root in two differently treated media was used in the following study for its possible contribution to our knowledge about the nature of the inhibitive effects by nitrates on nodulation of soybeans.

EXPERIMENTAL

Soybean plants were grown with their roots extending through soil to one part of which nitrates had been added and one part of which received no nitrate. This mode of division of the soil and the roots was accomplished by growing the soybean seedlings in soil in a paraffined screen pot immersed in a gallon jar of soil as previously described (1).

The soil used was Putnam silt loam collected from a field cropped to soybeans. The reaction of this lot of soil was altered from 5.6 pH to 6.8 pH by the addition of a mixture of 80% of finely ground lime and 20% of 60-mesh limestone. Into this lot of soil there were thoroughly mixed 15 parts of P_2O_5 as mono-calcium phosphate and 30 parts of MgO as magnesium sulfate per million parts of soil as calculated on the dry basis. The entire mass of this soil was then thoroughly inoculated with *Rhizobium Japonicum*.

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 500. Received for publication July 20, 1938.

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The author acknowledges the guidance and help of Professor W. A. Albrecht in this work, particularly in the preparation of the manuscript.

[3]Numbers in parenthesis refer to "Literature Cited", p. 914.

In the spring[4] two series of six pots, each consisting of a gallon jar of soil and one paraffined-screen pot of soil immersed into it, were prepared in duplicate.

In the paraffined-screen pot were placed 435 grams of soil and in the space about it in the gallon jar 2,000 grams. To the one series there were added only to the gallon jar 52, 83, 104, 144, 225, and 300 parts per million of soil of nitrogen as calcium nitrate. This was designated series A. The same concentrations were also added to the soil in the centrally immersed paraffined-screen pot and were designated series B. This gave equal concentrations of nitrate nitrogen in the treated zones but wide differences in the total nitrogen applied according to the differences in weights of soil in the two parts of the pot. In series B with 435 grams in the screen pot treated with nitrate, the total amount applied was only slightly more than one-fifth of that in series A where 2,000 grams of soil were so treated.

RESULTS

The data showing the number of nodules on the root segments of the inner and outer soil zones, the nodules per pot, their dry weights, and the weights of the plants are presented in Table 1. The average values for pots 4, 5, and 6, together with their comparative values calculated by fixing those for the check or untreated pot at 100 are shown in Table 2. Figs. 1 and 2 show the characters of the nodulation and root development of the nitrate-treated and the nitrate-free root segments of series A and B, respectively.

TABLE 1.—*Growth and nodulation of soybeans in consequence of varied zonal concentrations of calcium nitrate in the soil.*

Pot No.	Nitrate nitrogen added		Nodules per plant			Dry weight of nodules, mgms			Dry weight of tops per pot, grams
	P.P.M.	Mgms	Outer zone	Inner zone	Total per plant	Outer zone	Inner zone	Total per pot	
			Series A—Outer Zone						
1	52	104	6.0	31.5	37.5	48.0	300	348	6.3
2	83	166	3.4	24.0	27.4	27.0	45	72	5.2
3	104	208	0.8	35.0	35.8	0.1	87	87	7.0
4	144	288	1.0	34.0	35.0	0.01	60	60	5.8
5	225	450	0.0	27.5	27.5	0.0	45	45	6.8
6	300	600	0.1	22.0	22.1	0.0	23	23	5.7
			Series B—Inner Zone						
1	52	21	3.6	36.0	39.6	30	330	360	4.4
2	83	33	7.0	28.5	35.5	50	192	242	5.0
4	144	57	3.5	24.5	28.0	23	150	173	4.7
5	225	90	9.8	23.2	33.0	63	222	285	6.0
6	300	120	14.0	19.0	33.0	57	140	197	5.9
Check	0	0	7.5	32.0	39.5	39.0	362	401	4.6

[4]This experiment was tried in the winter with 10, 32, 52, 104, and 144 parts of nitrogen per million parts of soil. The plants made meager growth and grew tall and slender. Only a few plants produced nodules which were very few and very small. The nitrates did not affect nodulation at this season. Such abnormalities suggested the influence of unsuitable light conditions and therefore this experiment was repeated in the spring.

TABLE 2.—*Averages and comparative values of weights of tops, numbers and weights of nodules of pots 4 to 6 of each of two series, and of the check.*

Series	Nodules per plant			Dry weight of nodules per pot, mgms			Dry weight of plants per pot, grams
	Outer zone	Inner zone	Total	Outer zone	Inner zone	Total	
				Averages			
A......	0.4	27.8	28.2	0.0	44	44	6.1
B......	9.0	22.0	31.0	47.6	171	218	5.5
Check..	7.5	32.0	39.5	39.0	362	401	4.6
				Comparative Values			
A......	0.1	87	72	0	12	11	132
B......	120	70	79	124	47	54	119
Check..	100	100	100	100	100	100	100

ZONAL INFLUENCE OF NODULATION

It is evident from these results that both the numbers (formation) and the weights (development) of the nodules were decreased in the

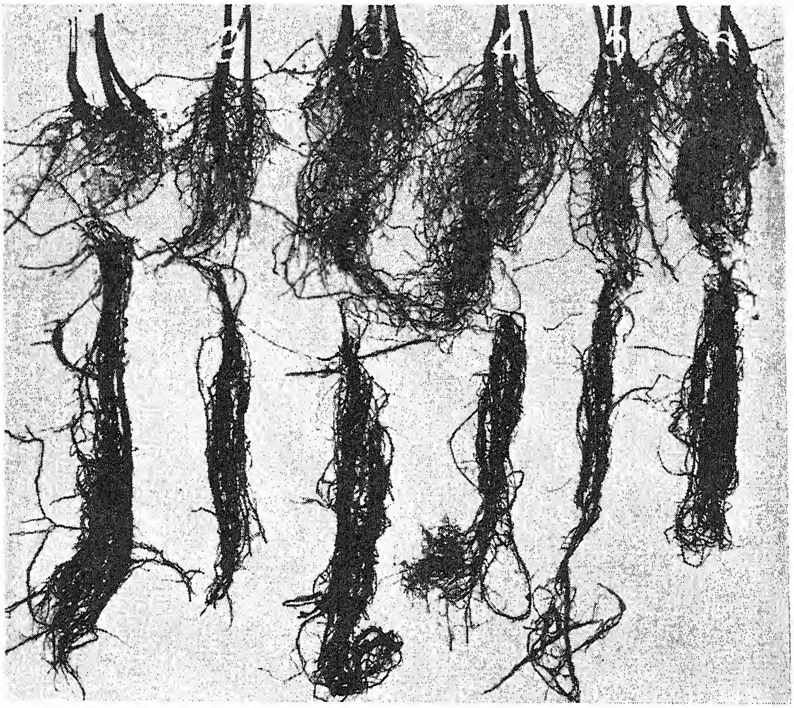

FIG. 1.—Soybean roots with segments (above) grown in the soil zone without nitrate additions and (below) the zone with added calcium nitrate as increasing amounts from left to right.

zones of nitrate placement in both series roughly according to the increase in concentration of nitrate nitrogen. In only one pot, No. 5, were the results not in agreement with this relationship. In concentrations of 144 mgms and more of nitrate nitrogen in the outer soil zone (series A), the applications of nitrate checked the formation and development of nodules therein almost entirely; but the nitrates added in the same concentration to the inner soil zone (series B) did not check nodule formation and development in this zone so completely.

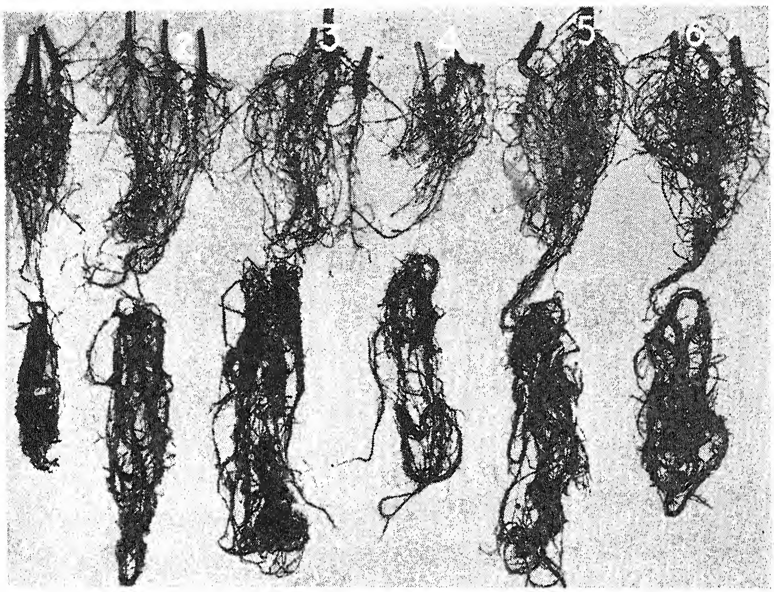

FIG. 2.—Soybean roots with segments (above) grown in the soil zone with added calcium nitrate as increasing amounts from left to right and (below) the zone without nitrate additions.

The more severely depressive effects by the larger amounts of nitrates placed in the outer soil zone (series A) extended to depress the development, or weight, of the nodules in the inner or nitrate-free zone. This is evident from the comparative values in Table 2 of the averages of the nodule weights. For the inner soil zone of series A the figure was only 12, while for the untreated check it was 100. The effect on reducing the number of nodules did not extend itself so pronouncedly into the inner or nitrate-free soil zone.

That the nitrates reduced the weight, or development, of the nodules more than they reduced their numbers, or formation, is shown in Table 3 consisting of some data assembled from Table 2. As for the weights of the nodules in comparative values, these are much lower in the zone of application than in the pot as a whole. As regards the number of nodules, those in the treated zone are not so much less

than the total number in the pot. In these respects these results agree in principle with those obtained by Giobel (2).

TABLE 3.—*Nodule numbers and weights in the nitrate-treated zone as compared to total nodules produced.*

Series	Comparative values	
	Weight	Number
A, outer zone, nitrates added	0	0.1
A, entire plat, total	11	72.0
B, inner zone, nitrates added	47	70.0
B, entire pot, total	54	79.0

EFFECT OF TOTAL AMOUNT OF NITRATE NITROGEN ON NODULATION

The total weights of nodules per pot tended to decrease not only according to the increase in the concentration of the nitrate nitrogen locally but also according to the total amount of nitrogen offered the plant. Since series B received only about one-fifth as much nitrogen per plant as series A, the comparative values in Table 2, namely, 100, 47, and 12 for the averages of the nodule weights in the pots 4 to 6 for the check, the series B, and the series A, respectively, show clearly the declining nodule weights with increasing amounts of total nitrogen offered the plants. From these data it appears, therefore, that the nitrates exercise injurious effects more on the development, or weight, of the nodules than on their formation, or numbers; and that the influence is greater not only with increasing concentrations but is more clearly related to the amount of nitrogen offered the plant.

The amounts of nitrate added controlled also the total weights of the tops as shown by the greater weights of tops in series A, receiving the larger total amounts of nitrate nitrogen.

DISCUSSION

The injurious effects on nodulation by the larger applications of nitrate nitrogen were found to be not entirely local. When the outer root segments were treated with nitrate, this depressed both the formation and the development of nodules in these root segments and extended the depressive effects significantly to the development but insignificantly to the formation of nodules within the non-nitrate-treated segments. The nitrate exerted its injurious effects on the development of nodules on those parts of the root lying along the path of the nitrate on its way to the stem from the points of absorption when the larger amounts of nitrate were used. This effect did not move in the reverse direction or towards those parts lying in the opposite direction from the points of absorption in the case of series B where the total nitrate supply was smaller but of the same concentration.

These results seem to indicate that the agency acting adversely on nodulation exerts its effect by hindering the development of the nodules over the entire root system. The total weight and the size of the nodules decreased with the increase in the total amount of nitrate

per plant, while the numbers were not so decreased. This indicates that the nitrate acts from within the plant after being absorbed and inhibits the development of the nodules without necessarily increasing the resistance by the plant to the entrance of the bacteria into the root tissue.

SUMMARY

Studies made of the effects of varying the nitrate concentration in two soil zones on the nodulation by soybeans gave decreased numbers and weights of nodules in the zones in which the nitrates were added. Such effects carried into the nitrate-free soil zone to decrease the weight of the nodules when the applications of nitrate were larger. When the same concentration of nitrates was applied in the inner zone and consequently less total amount of nitrogen, these effects were not transmitted so distinctly to the distal parts of the roots.

In general, the depressive effects were more pronounced on the weight or development than on the numbers of nodules. The decrease in total weight of nodules on the entire root system, as well as on the segments, was governed more by the total amount than by the concentration of nitrate nitrogen applied.

LITERATURE CITED

1. DOOLAS, GEORGE Z. Local variation of soil acidity in relation to soybean inoculation. Soil Science, 30:273–287. 1930.
2. GIOBEL, GUNNAR. The relation of the soil nitrogen to nodule development and fixation of nitrogen by certain legumes. N. J. Agr. Exp. Sta. Bul. 436. 1925.
3. STROWD, W. H. The relation of nitrates to nodule production. Soil Science, 10:343–356. 1920.
4. WILSON, J. K. Physiological factors influencing nodule formation. Cornell Univ. Agr. Exp. Sta. Bul. 386. 1917.

THE USE OF MORPHOLOGICAL CHARACTERS AS COMPARED WITH FLUORESCENCE TESTS WITH ULTRA-VIOLET LIGHT IN CLASSIFYING THE RYEGRASSES (*LOLIUM* SPP.) OF WESTERN OREGON[1]

H. H. RAMPTON[2]

RYEGRASS (*Lolium* spp.) is grown extensively for seed and forage in western Oregon. Over 90% of the ryegrass seed grown in the United States is produced in the Willamette Valley. The major portion of this seed is used for winter golf courses, winter lawns, and annual pastures in the southern states.

Domestic or Oregon ryegrass varies widely in plant and seed characters and is usually classified as *Lolium multiflorum* Lam. The Division of Seed Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture from seed characters considers it to contain the Italian type as grown in Europe and New Zealand, the Argentine-Italian type, and the perennial or English type. The seed is so variable in appearance that seed analysts are sometimes uncertain as to its definite classification. The general belief that all awnless ryegrass seeds are of the English or perennial type has resulted in the assumption that domestic or Oregon ryegrass contains considerable perennial stock.

The studies as outlined were made in an attempt to determine (a) the value of the fluorescence test in the classification of domestic ryegrass, (b) the approximate percentage of the perennial type in domestic ryegrass, and (c) possible types into which domestic ryegrass may be classified.

REVIEW OF LITERATURE

Schoth and Enlow[3] reported that domestic or Oregon ryegrass may be pure Italian, but is usually a mixture, predominantly Italian. Various combinations of Italian ryegrass and the perennial type may occur. They ascribed most of the intermediate types in domestic or Oregon ryegrass to natural crossing of the Italian and perennial types.

Hessing (7)[4] studied the genetics of ryegrass and concluded that while many types are relatively constant, great variation of characters occurs and in numerous combinations.

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[1]Contribution from the Oregon Agricultural Experiment Station, Corvallis, Ore., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Published as Technical Paper No. 286. Abstract of a thesis presented to the Department of Farm Crops, Oregon State College, in partial fulfillment of the requirements for the master's degree. Received for publication August 8, 1938.

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[3]SCHOTH, H. A., and ENLOW, C. R. The ryegrasses. U. S. D. A. mimeographed Circ. of Information. March, 1933.

[4]Figures in parenthesis refer to "Literature Cited", p. 922.

Italian and perennial ryegrass were described by Breakwell (1) Jepson (10), and Levy and Davies (11). The most important characters are listed as follows:

Lolium perenne L.—perennial ryegrass:
- Plants long lived
- Leaves mostly basal, numerous, comparatively narrow, folded in the bud
- Culms and convex side of rachis smooth
- Spikes erect, slender
- Spikelets not much longer than the outer glume
- Lemmas awnless
- Seedling growth slower than Italian
- Color of foliage dark green

Lolium multiflorum Lam.—Italian ryegrass:
- Plants short lived, taller than the perennial type
- Leaves borne mostly on the stems, rolled in the bud, wider and less numerous than the perennial type
- Culms and convex side of rachis often rough
- Spikes larger than the perennial type
- Spikelets much longer than the outer glume
- Lemmas awned, lower lemma of spikelet may be short awned or awnless
- Seedling growth rapid
- Color of foliage lighter green than the perennial type

Hayes and Garber (5) showed that in *Lolium multiflorum* 10.3% of the florets set seed when self fertilized and that 78.8% seed setting resulted from open pollination.

Jenkin (8, 9) found Italian and perennial ryegrass to be normally wind pollinated. Successful artificial crosses of *Lolium perenne* L. × *L. multiflorum* Lam. were reported. Hellbo (6) reported that Italian and perennial ryegrass are easily crossed.

Hellbo (6) working in Denmark, reported that Italian ryegrass seeds coming through the threshing and cleaning process in an awnless condition may be distinguished from perennial ryegrass seeds by certain characters of the lemma, palea, and rachilla and by the seed shape. Foy (4) of New Zealand and Colbry (2) of Oregon found the method used by Hellbo (6) to be unsatisfactory when applied to commercial ryegrass seed grown in New Zealand and Oregon, respectively.

Foy (4) applied the fluorescence test to the ryegrasses of New Zealand. He found that the seedling roots of Italian ryegrass produced fluorescence upon a white filter paper germinating base when placed over filtered ultra-violet light. Perennial ryegrass seedlings produced no fluorescence and seedlings of intermediate types were variable in reaction. Seedling fluorescence was found to be directly associated with the short life of ryegrass.

Linehan and Mercer (12, 13) of Ireland, after making studies similar to those reported by Foy (4), stated that awned seeds usually produced fluorescent seedlings that developed into normal Italian type plants. Non-fluorescent awnless seeds usually produced normal perennial plants. They considered the proportion of non-fluorescent awnless seeds in a lot of seed to be an approximate measure of the amount of perennial seed present.

These investigators reported fluorescence to be dominant in the F_1 progeny of fluorescent × non-fluorescent parent plants, and segregating in the F_2 progeny in an approximate 3 fluorescent to 1 non-fluorescent ratio. They found no evidence of linkage between fluorescence and awn presence or plant longevity.

Corkill (3) studied the inheritance of fluorescence in ryegrasses. His results indicated that fluorescence depends on a single Mendelian factor, segregating in the progeny of a hybrid plant in a 3 fluorescent to 1 non-fluorescent ratio.

Foy (4) stated that there is no definite knowledge of the substance responsible for fluorescence of reacting ryegrass seedlings. He suggested that the characteristic fluorescence may be due to the product of a reaction between an exudate, perhaps an enzyme, of the seedling root and filter paper germinating base.

EXPERIMENTAL METHODS

Nursery and laboratory trials were conducted with 288 lots of domestic, "Oregon Wild," imported Italian, and imported and Oregon-grown perennial ryegrass seeds obtained from the principal ryegrass seed-producing regions of the world.

The nursery planting was made on November 4, 1931, in rows 16 feet long, spaced 2 feet apart.

NURSERY OBSERVATIONS

Field observations on the nursery were made periodically from time of seedling emergence to April 20, 1933. Field notes were recorded on persistence, winter-hardiness, growth type, dates of spike emergence, flowering, and seed maturity, vigor, and plant height.

In 1932, 10 representative single plants were harvested from each of 59 representative lots in the nursery at the time of seed maturity. These were cured and stored for later laboratory observations including fluorescence tests of germinated seeds and detailed plant observations covering plant height, number of internodes, culm diameter, stem texture, spike length, number of spikelets per spike, length of the outer glume, and awn length.

FLUORESCENCE TESTS WITH ULTRA VIOLET LIGHT

The equipment used in this test was the same as used for similar work by the Division of Seed Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture.

The fluorescence test was applied to seedlings of some of the original seed lots of domestic, imported, and Oregon-grown perennial, Imported Italian, Argentine, and "Oregon Wild" ryegrass, and also to their 1932 nursery-grown progeny.

Germinating and testing was done in the laboratory. Each test was conducted with duplicated 100 seed samples placed on moist discs of white filter paper in 3½-inch petri dishes, each dish containing 25 seeds. Counts of fluorescent seedlings began on the fifth day. This work was done at night because complete darkness aided in making accurate counts. All reacting seedlings did not fluoresce at the same growth stage, so counts were made at 2-day intervals until the eighteenth day.

RESULTS

THE NURSERY

Seedlings of domestic ryegrass emerged about 6 days earlier than any of the other lots and made the most rapid winter growth. Perennial ryegrass seedlings grew little in height during the winter but made considerable crown development.

Nursery observations during 1932 gave little evidence in support of the general belief that much perennial stock exists in domestic rye-

grass. The domestic ryegrass plants were, however, extremely variable in appearance. Wide variations in width, position, and number of leaves, general growth habit, color, vigor, number and texture of culms, spike type, and awn character were observed. Fig. 1 shows several common variations of spike type found in domestic ryegrass.

Only a small number of plants in domestic ryegrass possessed the narrow dense dark green leaves, comparatively short culms, and entirely awnless seeds characteristic of the perennial type. These were chiefly confined to a few lots, particularly lot No. 37, that appeared to be about 90% ordinary domestic and 10% perennial ryegrass.

These observations were further substantiated after the severe winter of 1932–33, when domestic ryegrass was almost 100% winter-killed and perennial ryegrass survived. Table 1 shows winter survival of a number of the lots in this trial. All perennial ryegrass lots were quite winter-hardy. The domestic lots in Table 1 showed 0 to 10% winter survival. Lot No. 37 survived 10% and was the only one of this group exhibiting the morphological characters of perennial ryegrass in the surviving plants.

Italian ryegrass lot No. 46 imported from Scotland survived 75%, indicating it to be hardier and perhaps naturally longer lived than domestic ryegrass. No perennial type plants were observed in this lot.

"Oregon Wild" ryegrass lot No. 66 had 60% winter survival. Most of the surviving plants were perennial-like in appearance. This observation checked quite closely with general observations of wild ryegrass plants growing along roadsides, fences, and in waste areas.

This wild stock contains a fairly high percentage of perennial-like plants, many of which bear definitely awnless seeds. These plants were especially prominent in March, following the severe winter of 1932–33 when most domestic ryegrass was winter killed. The presence of this type of ryegrass growing wild in a great many places suggests that perennial ryegrass may have been an important component of the ryegrass seed crop at an earlier date. Some authorities believe this to have been the case; the perennial ryegrass gradually losing its identity in commercial seed fields because of the more profuse seeding qualities of domestic ryegrass and as a result of natural hybridization. On this basis, the wide variation in domestic ryegrass might be explained.

Plant observations in the laboratory showed perennial ryegrass to be invariably smooth-stemmed, quite constant in spike characters, and in general, comparatively uniform. Imported Italian ryegrass was also quite uniform, particularly with respect to length of the outer glume and the long awned character. Stem texture was variable. Domestic ryegrass showed wide variation in all characters studied. The variation between different lots was much less striking than the variation within lots. Awn studies showed variation from long heavy awns to awnless seeds. Careful checking showed that many weak-awned domestic ryegrass plants lost their awns in the field, chiefly as a result of wind agitation.

Attempts to classify domestic ryegrass into distinct types were abandoned when it became apparent that classification would be of little practical value because of the numerous plant types involved.

FLUORESCENCE TESTS WITH ULTRA-VIOLET LIGHT

Certain substances have the property of absorbing the short, invisible ultra-violet rays and omitting longer, visible light rays. This

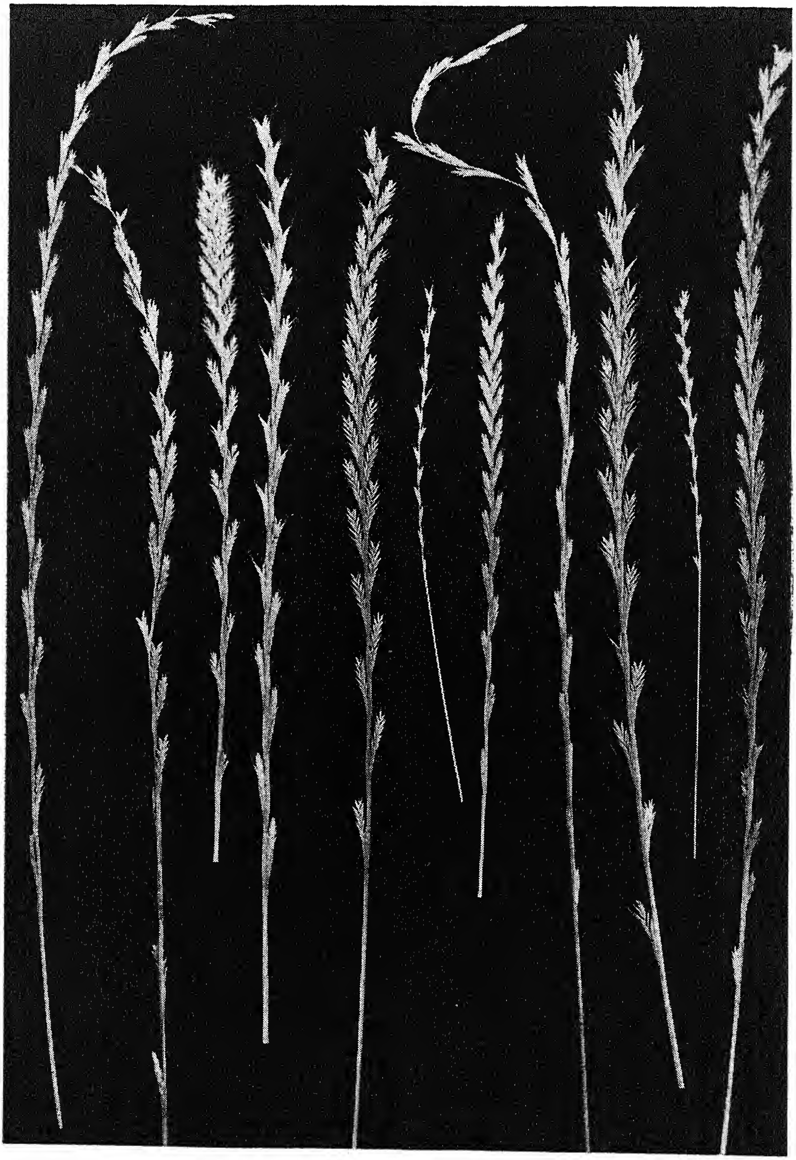

FIG. 1.—Variations of spike type commonly found in Oregon-grown domestic ryegrass.

is known as fluorescence. The results of fluorescence tests applied to the seedlings of some of the ryegrasses under trial are shown in Table 1.

TABLE 1.—*Percentage winter survival and results of fluorescence tests on seedlings of various lots of ryegrass including the 1931 (original) lots and their 1932 nursery progeny.*

Lot No.	Year	Origin and species	Survival winter 1932–33 %	Fluorescent seedlings %
1	1931	Domestic *L. multiflorum*	5.0	88.0
1	1932	Domestic *L. multiflorum*		92.0
2	1931	Domestic *L. multiflorum*	0.0	87.0
2	1932	Domestic *L. multiflorum*		93.0
3	1931	Domestic *L. multiflorum*	5.0	90.0
3	1932	Domestic *L. multiflorum*		94.0
4	1931	Domestic *L. multiflorum*	0.0	92.0
4	1932	Domestic *L. multiflorum*		93.0
5	1931	Domestic *L. multiflorum*	0.0	87.0
5	1932	Domestic *L. multiflorum*		95.0
6	1931	Domestic *L. multiflorum*	0.0	83.0
6	1932	Domestic *L. multiflorum*		92.0
7	1931	Domestic *L. multiflorum*	0.0	93.0
7	1932	Domestic *L. multiflorum*		100.0
8	1931	Domestic *L. multiflorum*	5.0	89.5
8	1932	Domestic *L. multiflorum*		94.0
9	1931	Domestic *L. multiflorum*	0.0	86.5
9	1932	Domestic *L. multiflorum*		95.0
10	1931	Domestic *L. multiflorum*	0.0	91.0
10	1932	Domestic *L. multiflorum*		91.0
11	1931	Domestic *L. multiflorum*	0.0	87.0
11	1932	Domestic *L. multiflorum*		92.0
12	1931	Domestic *L. multiflorum*	0.0	92.0
12	1932	Domestic *L. multiflorum*		94.0
37	1932	Domestic *L. multiflorum*	10.0	98.0
42	1931	Domestic *L. perenne*	90.0	13.0
42	1932	Domestic *L. perenne*		41.0
43	1931	Imported *L. perenne*	95.0	24.0
43	1932	Imported *L. perenne*		54.0
44	1931	Scotland *L. perenne*	95.0	18.0
44	1932	Scotland *L. perenne*		40.0
45	1931	N. Zealand *L. perenne*	85.0	50.0
45	1932	N. Zealand *L. perenne*		86.0
46	1931	Scotland *L. multiflorum*	75.0	80.0
46	1932	Scotland *L. multiflorum*		98.0
52	1931	Argentine *L. multiflorum*	0.0	76.0
52	1932	Argentine *L. multiflorum*		76.0
53	1931	N. Zealand *L. perenne*		0.0
54	1931	N. Zealand *L. perenne*		5.0
66	1931	"Oregon Wild" L. sp.	60.0	70.0

Differences in fluorescence of seedlings from the 1931 (original) and 1932 (nursery-grown) seed of the same lots were generally apparent. The averages of fluorescence for the lots Nos. 1 to 10 in Table 1 were 88.70 and 93.90% for the 1931 and 1932 crop seedlings, respectively, or a difference of 5.20%. These results seem to support the theory of Foy (4) who suggested that an enzyme may be responsible for the fluorescence of reacting seedlings. The enzyme activity of seeds is known to decrease with age.

When the results of the fluorescence tests on domestic ryegrass are used as a guide, only lot No. 7 and two others not recorded in Table 1 appear to be 100% non-perennial. A number of other domestic lots fluoresced 98%. Several awned non-fluorescent seedlings were observed in some of the tests.

Domestic lot No. 37 that appeared to contain about 10% of perennial ryegrass in the nursery fluoresced 98%. This indicated that some or all of the perennial type plants observed may have been intermediate forms having perennial-like plant characters but producing fluorescent seedlings. A 1931 seed remnant of this lot was not available for testing its fluorescence before being grown in the nursery. Colbry (2) reported 88.89% to 94.21% fluorescence in samples of domestic ryegrass seeds. The average of fluorescence for all 1932 lots of domestic ryegrass used in the trials was 94.20%.

The findings of Corkill (3), Foy (4), and Linehan and Mercer (12, 13) when applied to these data indicate that the domestic ryegrass used in these trials averaged approximately 5% perennial, or perennial and non-fluorescent intermediate forms, and 95% Italian and fluorescent intermediate forms of ryegrass. On the basis of nursery behavior, however, this domestic ryegrass contained less than 1% of perennial or intermediate forms resembling perennial ryegrass. Linehan and Mercer (12, 13) indicated that the fluorescence test may be used only for making approximate determinations in classifying ryegrass seeds. The findings of these investigators concerning the absence of linkage between fluorescence and awn presence account for the awned non-fluorescent domestic ryegrass seedlings observed.

Evidence was obtained of crossing between lots of domestic and perennial ryegrass in the nursery. A comparison of the fluorescent character of seeds of perennial ryegrass before and after being grown in the nursery indicated that crossing had taken place. A few lots of domestic ryegrass grown adjacent to lots of perennial stock also showed evidence of crossing.

"Oregon Wild" ryegrass fluoresced 70%. This observation checked in a general way with nursery and field observations and was considered to indicate the presence of perennial ryegrass.

SUMMARY AND CONCLUSIONS

Nursery trials and fluorescence tests were conducted with numerous lots of ryegrass seeds obtained from growers in western Oregon and from the important foreign ryegrass seed-producing countries.

Domestic ryegrass as commonly grown in western Oregon is a mixture of types, most of which are closely associated with the European Italian ryegrass type, and a few that are perennial-like. "Oregon Wild" ryegrass contains many perennial-like plants, suggesting that perennial ryegrass may have been an important component of the ryegrass seed crop in the past. On this basis, authorities sometimes explain the wide variability of domestic ryegrass.

There is little evidence in support of the belief that an appreciable quantity of perennial ryegrass now exists in commercial domestic ryegrass. The fluorescence test indicated that domestic ryegrass is

approximately 5% perennial or perennial and non-fluorescent intermediate forms of ryegrass. The nursery behavior, however, indicated less than 1% of perennial-like plants.

Domestic ryegrass and the Italian ryegrass of New Zealand and Ireland appear to be quite similar in reaction to the fluorescence test.

The fluorescence test cannot be used as an infallible guide in classifying questionable lots of Oregon-grown domestic ryegrass seed. Some of the domestic ryegrass seedlings used in these trials showed no fluorescence, even though they were chiefly not of perennial stock. An experienced seed analyst thoroughly familiar with the seed characters of the various ryegrass types can, in most cases, quite accurately evaluate such seed samples, but the fluorescence test is useful in the classification of the general run of domestic ryegrass seed and in making approximate determinations. It is also useful in serving as a check on the work of seed analysts.

Classification of domestic ryegrass into definite types was impracticable because of the numerous combinations of characters encountered.

LITERATURE CITED

1. BREAKWELL, E. Popular descriptions of grasses: The rye or Lolium grasses. Agr. Gaz. N. S. Wales, 29:274–281. 1918.
2. COLBRY, VERA L. A study of western grown Italian ryegrass seed. Unpublished data. Ore. Agr. Exp. Sta. 1933.
3. CORKILL, L. Inheritance of fluorescence in ryegrass. Nature, 130:134. 1932.
4. FOY, N. R. Use of ultra-violet light in diagnosis of types of ryegrasses in New Zealand. N. Z. Jour. Agr., 43:389–400. 1931.
5. HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co. Ed. 2. 1927.
6. HELLBO, E. The distinction between seeds of Italian ryegrass and perennial ryegrass, and between seeds of ryegrass and meadow fescue. Int. Rev. Agr., 4:155–164. 1926.
7. HESSING, V. Investigations on the variability and heredity of the characters of certain species of Lolium. Int. Inst. Agr., 11:318–319. 1920.
8. JENKIN, T. J. The artificial hybridization of grasses. Welsh Plant Breeding Sta. Bul. Ser. H, No. 2. 1924.
9. ————. Self and cross fertilization in *Lolium perenne* L. Jour. Gen., 17:11–17. 1926.
10. JEPSON, W. L. Manual of the Flowering Plants of California. University of California, Berkeley: Associated Students Store. 1925.
11. LEVY, E. B., and DAVIES, W. Perennial ryegrass strain investigation. Single plant studies at the plant research station. N. Z. Jour. Agr., 41:147–163. 1930.
12. LINEHAN, P. A., and MERCER, S. P. The varietal purity of commercial Italian ryegrass. Proc. Int. Seed Testing Assoc., 4:153–160. 1932.
13. ————, ————. Fluorescence of Lolium seedlings in ultra-violet light. Nature, 131:202–203. 1933.

SHELTERBELT PLANTING REDUCES WIND EROSION DAMAGE IN WESTERN OKLAHOMA[1]

J. H. Stoeckeler[2]

SHELTERBELTS of trees and shrubs have long been used in Russia, Italy, Hungary, and Canada and in certain fruit growing sections of our own Pacific Coast to give protection to crops and reduce wind erosion. They have been used to some extent in the subhumid Great Plains area where tree growing is a difficult proposition and success depends on correct choice of planting site, careful ground preparation before planting, proper selection of species, and clean tillage for three to 5 years after planting.

One of the most outstanding areas in the Great Plains in which tree planting has been carried on with considerable success for over 30 years is located in northeastern Greer County, Oklahoma, about 15 miles northeast of the town of Mangum. The writer will endeavor to record here for the benefit of those interested in wind erosion his observations of this planting program and a resumè of information obtained by personal interview with a considerable number of farmers in this vicinity.

CLIMATE, SOIL, AND CROPPING PRACTICES

The area under discussion has a mean annual rainfall of about 27 inches of which almost 70% falls between April 1 and September 30. The evaporation from a free water surface for the six summer months is close to 48 inches.

The soils are generally sandy and one of the predominant soils is the Miles series which has a loamy fine sand to sandy loam topsoil from 6 to 15 inches thick, lying over a sandy-clay subsoil. The sandy topsoil is an excellent "sponge" for the rapid absorption of rainfall which is stored in the more impervious subsoil where it is held within easy rooting depth of crops. It has been observed that if wind erosion removes this top layer of sandy soil, crop yields decrease considerably, due, very likely, to lower infiltration rate, higher runoff, and greater evaporation losses.[3]

The principal crops are cotton and several types of grain sorghums, such as kaffir and milo. Soybeans and cowpeas are used occasionally in rotations to build up the soil.

Yields of cotton vary according to season, but generally range between ¼ and ½ bale per acre. Kaffir and similar feed crops yield from 15 to 30 bushels per acre. Crop yields are good enough so that the land cannot be considered submarginal.

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[1]Contribution from the Lake States Forest Experiment Station, U. S. Department of Agriculture, University Farm, St. Paul, Minnesota. Maintained in cooperation with the University of Minnesota.

[2]Associate Silviculturist.

[3]It was suggested by Dr. H. J. Harper, Professor of Soils at the Oklahoma Agricultural Experiment Station, who reviewed this paper that loss of soil fertility, especially nitrogen, would also be a factor in reducing yields.

THE PROBLEM

The principal farming problem on the sandy soils in this area is sand drifting which causes damage by uncovering recently sown seed, cutting off tender shoots of crops when only a few inches high, and by burying or uncovering the plants. Besides the immediate damage to the crop, the value of the soil itself is reduced because of exposure of the subsoil and the formation of ridges and hummocks in the fields and along fence rows. Buildings and roads are also sometimes damaged by the drifting sand.

Cotton is especially susceptible to damage and is often planted from two to four times before a stand is obtained. This sometimes necessitates plantings made as late as June 15 to July 1, with the result that a 15 to 30% loss in yield may be incurred, chiefly due to late planting, with a high proportion of the flowers and unripe bolls injured by frosts in fall and consequently never maturing. If successful early planting is obtained, a much higher percentage of the crop matures and the total yield is considerably increased. The solution of the problem lies in protecting the soil and reducing the velocity of the wind during this critical period. (See Fig. 1.)

SOLUTION OF THE WIND EROSION PROBLEM

Over 30 years ago the farmers in this section of Oklahoma began the planting of single-row shelterbelts of cottonwood and mulberry spaced parallel to each other at distances of 1/8 to 1/4 mile apart and running in an east-west direction. This direction was chosen because it was at right angles to the direction of the most damaging winds which usually blow from the south. In some instances the east-west belts were supplemented with north-south windbreaks.

FIG. 1.—Cotton field on the Miles fine sandy loam protected by shelterbelt.

In addition, a system of strip cropping was adopted in which narrow strips of grain sorghum or other feed crops were alternated with cotton (Fig. 2). The strips varied from 5 to 10 rods in width and were planted in an east-west direction. It was observed that the strips of cane were of considerable value in later summer and fall in reducing the drifting of sand and were even effective in winter if left standing in the field.

The resulting program of tree planting and strip cropping has almost completely solved the wind erosion problem on many farms where serious crop losses had been sustained previous to these farmers' pioneering efforts in wind-erosion control.

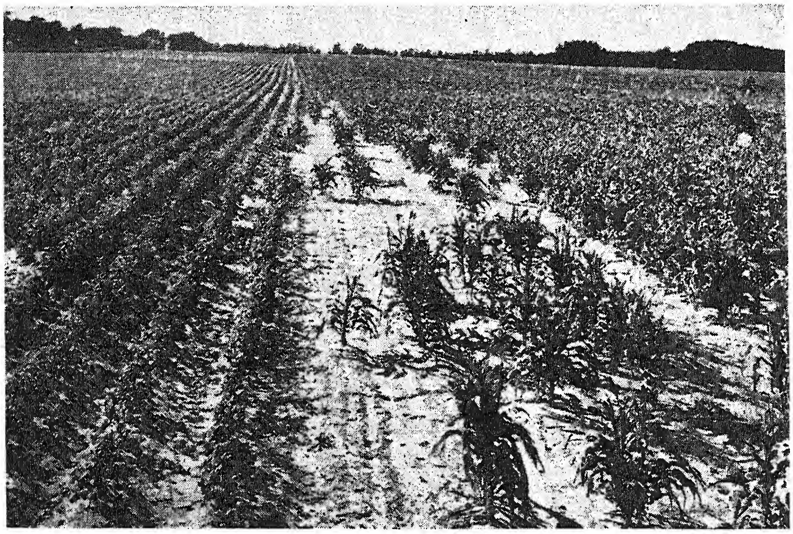

FIG. 2.—Strip cropping with maize and cotton. Note shelterbelts in background.

DETAILS OF THE SHELTERBELT PLANTING

The planting of the shelterbelts by these farmers on their own resources, generally with no state or government subsidy, was prompted by several things. First, it was soon observed that strip cropping alone was not a complete solution of the sand drifting problem, especially in late spring during and immediately following planting of the row crop. Secondly, there was a need for fence posts and, to some extent, fuel.

Number of rows.—Inspection of many fields protected by shelterbelts showed that single or double rows of cottonwood or mulberry were practically as effective as windbreaks composed of 10 to 15 rows, required less labor, and occupied less ground.

Growth rate, cutting methods, and longevity of trees.—The trees grew at a surprising rate, such species as cottonwood attaining average heights of 30 to 40 feet in 8 to 10 years and an ultimate height of 60 to 70 feet in 30 years. (See Figs. 3 and 4.) Mulberry attains heights

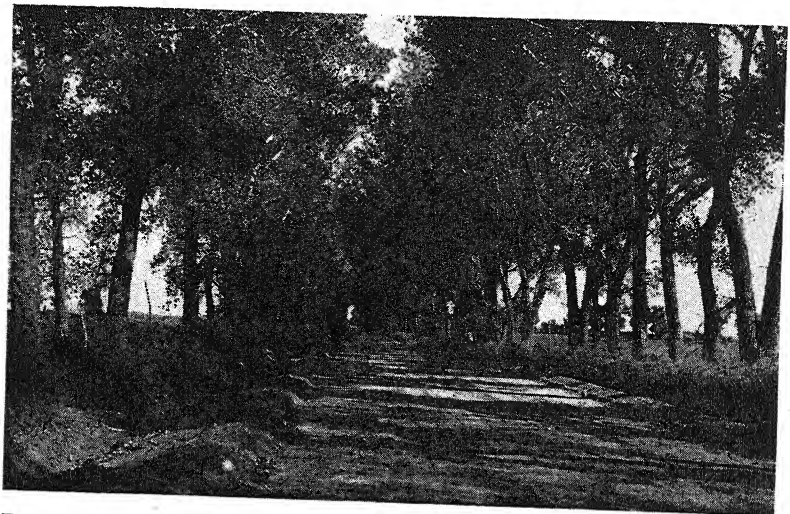

FIG. 3.—Cottonwood shelterbelt planted along road east of Willow, Oklahoma, serves dual purpose of beautifying road and reducing sand drifting on adjoining fields.

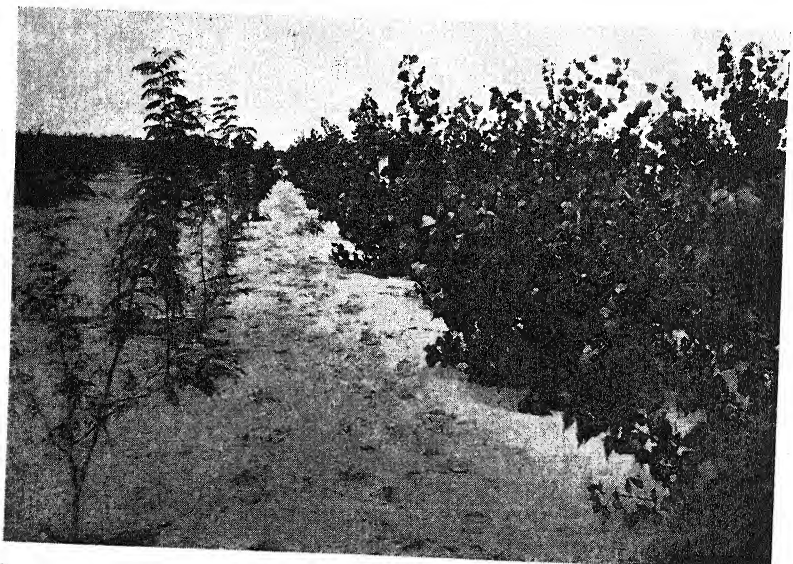

FIG. 4.—Exceptional growth on one-year-old Forest Service demonstration planting of honey locust and cottonwood near Mangum, Oklahoma. Trees are 7 to 10 feet high and already partially effective in reducing sand drifting.

of 20 to 25 feet in 10 years and is especially popular because it produces a desirable fence post in about 15 years.

A point of great interest to the writer was the manner in which single rows of mulberry trees were made to serve the dual purpose of

wind-erosion control and production of fence posts. The farmer merely cut a post out of the top of a fairly large mulberry tree, thus causing it to stool out, and thereafter a continuous supply of posts was obtained by judicious cutting of several stools or sprouts from each tree at intervals of 4 or 5 years. This could be done without seriously reducing the windbreak value of the tree. Where this modified "coppicing" method of cutting was utilized, the trees had a tendency to attain less than normal height and the parallel rows could not be over $\frac{1}{16}$ mile apart if they were to function effectively as windbreaks.

On the basis of existing shelterbelts on the sandy soils, it appears that the trees will keep in good vigor from 30 to 50 years and begin to be somewhat effective in wind erosion control when they are 3 to 5 years old.

A point of major importance in this section of Oklahoma is the fact that trees reach approximately twice the height and longevity on deep sandy soils that is attained on fine-textured soils, such as silt loams and clay loams.

Necessity of planting only on sandy soils.—In view of the above statement, a brief explanation is necessary. The Lake States Forest Experiment Station has determined on the basis of moisture samplings made in western Oklahoma that there is a much greater amount of available moisture within rooting depth of trees in the sandy soils and that there is deeper storage of the rainfall with consequent slower exhaustion of available moisture by deep-rooted plants. These observations are verified indirectly by Musgrave and Free[4] whose data on infiltration rates for the Cecil series show a marked superiority in favor of sandy soils, and it is logical to assume that the same trend would hold in western Oklahoma over a range of soil textures.

Finnell's[5] data on moisture utilization of the heavy soils in western Oklahoma indicate that as little as 25% of the total rainfall may be stored in the ground for actual use by crops. The inference to be drawn from his work is that fine-textured soils, in spite of their higher water-holding capacity, are actually much more droughty than sandy soils underlain by a sandy clay of reasonably good water-retention ability.

As a side light on this point, it might be of interest to state that the superiority for tree growing of sands over fine-textured soils is much more pronounced in the southern than in the central or northern part of the Great Plains, where rainfall does not attain the same intensity and where evaporation rate is less than farther south. The writer seriously questions the feasibility of shelterbelt planting on most of the fine-textured soils in the southern Great Plains as a wind control measure. Since the problem on such soils is largely one of storing moisture in the ground, such measures as terracing, contour listing, basin listing, summer fallowing, and crop rotation are much more

[4]Musgrave, G. W., and Free, G. R. Preliminaty report on the determination of comparative infiltration rates of some major soil types. Trans. Amer. Geophys. Union, 18th Ann. Meet. 1937.

[5]Finnell, H. H. The utilization of moisture on the heavy soils of the southern Great Plains. Okla. Agr. Exp. Sta. Bul. 190. 1929.

practicable. Strip cropping is no doubt also of value in reducing wind erosion on these "tight" soils.

The difference in tree growth in soils of different textures is so striking in this part of Oklahoma that the casual observer can determine the texture of the soil from a distance of several miles merely by watching the relative abundance and height of the tree belts. Any upland area which is supporting numerous belts of tall vigorous trees will invariably be sandy in texture.[6] Conversely, on the fine-textured soils, especially on clay or clays loams, the belts are generally few, scrubby, short-lived, and riddled by borer damage.

SAPPING AND SHADING EFFECTS OF SHELTERBELTS

Numerous observations of windbreaks in this section of Oklahoma indicate that one- to three-row belts of trees will prevent or reduce crop production on a strip of land equal in width to approximately 1 to 1½ times the height of the taller trees. About two-thirds of the loss occurs on the north and one-third on the south side of the shelterbelt, the difference being due mainly to shading effect which is especially pronounced on the north side of the tree rows.

If this area is computed for a farm with an adequate system of windbreaks, it is found that eventually from 5 to 15% of the gross acreage will be removed from crop production, depending on the species, interval, and width of the protecting tree belts. Due allowance must be made for the fact that where crop rows are at right angles to tree rows planted along fence rows or property lines, not all of the idle land at the end of the crop rows can be justly charged as being taken up by the trees, because some bare land must be left for turning even if there are no trees planted along the property line. The point is that this waste space might better be occupied by a useful tree crop than by the usual stand of weeds or brush.

The writer asked a number of cotton farmers how it would be possible to justify the planting of the trees from a farm management viewpoint. The consensus of opinion was that the reduction of crop acreage due to sapping and shading effect of the trees was more than offset by protection to the soil, increase in yield on the remaining crop land, and value of the windbreak as a source of fence posts and fuel. Possibly they overrate the value of these shelterbelts, but it is probable that their cumulative experience over a period of at least 30 years and empirically determined deductions are technically sound.

SUGGESTED IMPROVEMENTS IN SHELTERBELT PLANTING

On the basis of observation of shelterbelt influences, supplemented by actual field data on moisture sampling and sapping and shading effects of the tree belts, several minor changes could be made to improve the benefits to be derived from tree planting in this section of the Great Plains, as follows:

[6]It must be recognized that on the extremely sandy areas, for instance dune sand, trees may be short-statured because of low water-holding capacity and lack of available nutrients. The term "sandy" as used here in connection with agricultural soils refers to soils which are classed as loamy sands or sandy loams.

1. A system of tree planting will be most effective if cropping areas are broken up into units from 10 to 40 acres in size and completely surrounded by shelterbelts, as shown in plans 1 to 4 in Fig. 5. If belts are planted only in an east-west direction, no protection is obtained against winds that are parallel in direction with the tree rows. The tree-planting plan followed need not be in as rigid a geometric pattern as shown. For instance, a farm may have a few very unstable knolls of sand which would be completely protected by windbreaks enclosing 10-acre blocks. The rest of the farm could be broken up into 20- or even 40-acre fields. Property boundaries, fence lines, topography, and land use will influence exact location of the tree strips.[7] Plan 2 is an especial favorite with farmers with whom demonstration plantings are made by the U. S. Forest Service in its Prairie States Forestry Project.

2. It would be much safer to adopt a two- or three-row belt because of the added protection given. It has been observed that cottonwood, as it approaches maturity, sheds its lower limbs, causing sizable gaps in the lower half of the belt which results sometimes in scouring of soil from the roots of the trees. Moreover, if a gap occurs in a single-row belt, there is created a channel through which the wind surges with increased velocity and destroys crops in a fan-shaped area on the lee side of the belt. Single rows of mulberry will, of course, make good windbreaks if the interval between belts is reduced. A fairly effective belt can be obtained by alternating cottonwood and mulberry trees in a single row.

On very unstable soils the east-west belts should not be over 1/8 mile apart, if they are to be effective. In other words, on such soils the effective zone of influence is about 10 times the height of the taller trees in the windbreak. Cottonwoods 70 feet high will generally prevent serious sand movement in a zone up to 700 feet on the lee side, providing the wind is fairly close to a right angle to the belt.

If no cottonwood is planted and single rows of mulberry or similar shorter growing species are used, the east-west belts should preferably be 1/12 to 1/16 mile apart.

3. It is advisable to use a greater variety of species, including honey locust, osage orange, green ash, apricot, jujube, and catalpa. Species like black locust, ailanthus, sand plum, or soapberry, which sucker profusely, might best be avoided, although some farmers think highly enough of black locust as a fence post producer so that they will plant it anyhow. Species producing fruit or nuts should be placed in the south row. Lilac, desert willow, and similar flowering shrubs are valuable next to roads. Dense, low-growing shrubs are not favored in interior windbreaks because of their tendency to build up a high ridge of sand along the shrub row. Hardy conifers, such as red cedar, Ponderosa pine, and Austrain pine, can be used to a limited extent along roads or near buildings.

4. Summer fallowing and similar moisture-storing measures should be used for at least one year before planting if the soil moisture to a

[7]On soils which are sufficiently fine-textured to yield any appreciable runoff from heavy rains, consideration should be given to the possibility of planting on the contour, as has actually been done on an experimental scale by the U. S. Forest Service in the plains region.

depth of 4 feet is not adequate. Soil moisture is more than likely to be lacking on areas which previously were occupied by sod, weeds, brush, or natural tree growth, alfalfa, or any other close-growing crops.

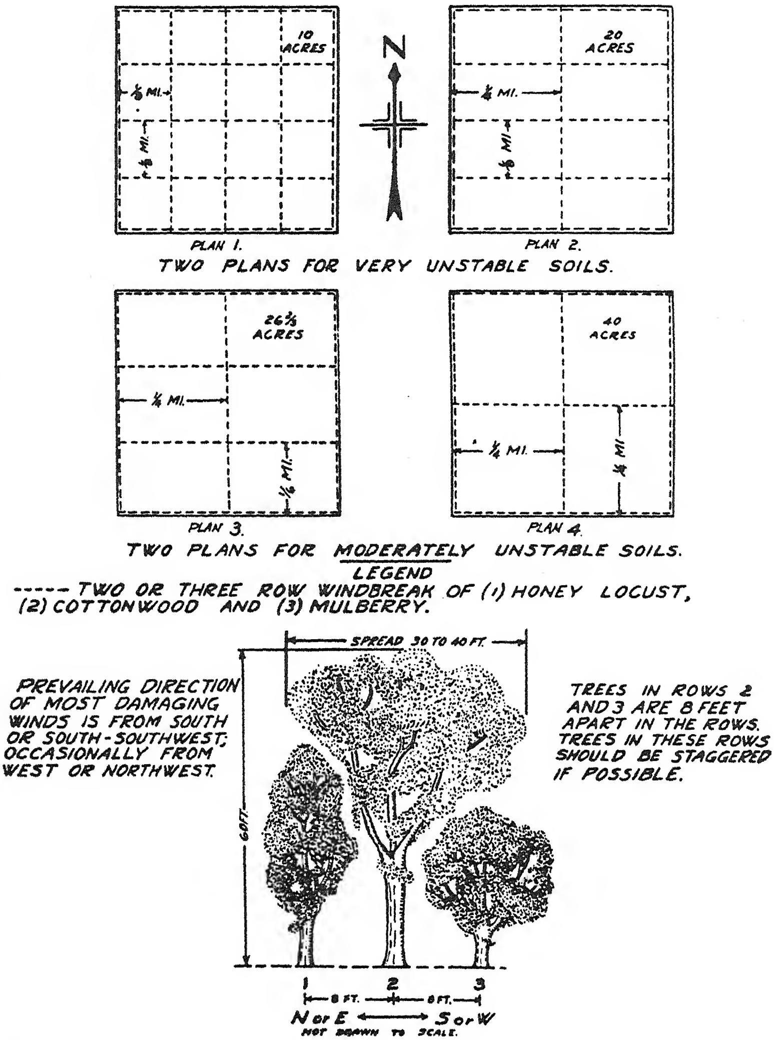

FIG. 5.—Scheme of planting windbreaks to minimize sand drifting in western Oklahoma and northwest Texas.

5. Costs of establishment can be reduced by having a carefully prepared plan, staking or marking out the area in such a manner as to have straight rows, and using sturdy, well-rooted nursery stock with a stem caliper at the ground line of ¼ inch or more. Planting stock should be grown in a latitude similar to the planting site and

should be of acclimatized native or near-native seed sources to assure adaptability to the planting site. With these precautions, the cost of the initial investment will be from \$0.50 to \$1.50 per acre protected. This initial investment can be justified in view of the ultimate benefits derived from the planting.

SUMMARY

1. Shelterbelt planting has been used for over 30 years as a means of reducing wind erosion on agricultural land in Greer County, Oklahoma.

2. It was found most feasible on the sandy soils, chiefly on the miles and associated series of similar texture and crop adaptability.

3. The windbreaks were generally parallel single rows of cottonwood or mulberry planted in an east-west direction at right angles to the most damaging prevailing winds.

4. Cotton responded especially well to protection of tree belts.

5. A wind erosion control program involving use of tree planting combined with strip cropping is described.

6. The design and width of shelterbelts depends on the soils and agricultural crops grown and must be varied accordingly.

7. Trees cannot be expected to live indefinitely on the Great Plains and even on the more favorable soils must be replaced at intervals of 30 to 50 years. Although some cases of regeneration from sprouts or natural seeding have been observed, it is the writer's opinion that this second crop of trees or sprouts will not attain the ultimate height or longevity of the first crop because of exhaustion of the deeply stored (6 to 25 feet) subsoil moisture by the first tree crop.

8. Shelterbelt planting is not a panacea for any and all wind erosion problems, but it certainly is feasible in those areas where trees will grow successfully and where benefits derived in crop and soil protection, wood products obtained, and increase in sales value of the farm justify the expenditure involved in planting and aftercare.

ANTHESIS IN FLAX[1]

B. S. Kadam and S. M. Patel[2]

THE area planted to flax (*Linum usitatissimum* L.) in India is a little over 3½ million acres. Nearly 49% of this lies in the alluvial Indo-Gangetic tract in the north eastern portion of the country. Most of the remaining area is confined to what is known as the black cotton soils of peninsular India. These two tracts not only differ in the nature of the soil, but also in climatic conditions, and in both the regions flax is a cold season crop. In the alluvial tract, however, flax matures late and has a much branched and spreading habit of growth with an abundant but shallower root system. The peninsular kind is a quick-maturing type with few erect branches and a deeper root development. It has a larger grain which is richer in oil content than the alluvial type.

Flax is grown entirely for oil in India, and considerable genetic improvement of the crop has been and is being made in the important flax-growing provinces. Except for that reported by the Howards (2, 3),[3] there does not appear to be any detailed account of anthesis in flax reported in India. The studies of the Howards deal with the alluvial types exclusively. It was thought, therefore, that observations on peninsular types would be of special interest and might present some new features, besides being useful in determining a suitable technic for hybridization. The results of such observations are briefly reported in this paper.

REVIEW OF LITERATURE

The Howards (2) found that the time of blooming of flax flowers of the alluvial type is influenced more by temperature and humidity than by varietal differences. On warmer days flowers open earlier than on colder and dewy mornings. For example, on the very warm day of February 10, 1916, flowers began to show signs of opening as early as 3 a.m.; whereas on the cold day of February 9 they began to open as late as 7.30 a.m. As a rule flowers fully opened between 8.15 a.m. to 9 a.m. on a warm day and between 10 a.m. to 12 noon when the day was cold. The Howards also found that the petals were shed by the evening of the same day on which the flowers opened. A few reopened the second day, the number increasing if the day was cold or cloudy.

The flowering and pollination of European types of flax has been studied by Tammes (5) and by Fruwirth (1). The former has studied the morphology and anthesis of flax flowers in detail. According to Howard and Khan (3), Tammes observed that in Holland flowers commenced to open as early as 5 o'clock in the morning, the petals shedding by 10 to 11 a.m. Flowers rarely opened again the following morning.

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[1]Contribution from the section of the Crop Botanist, Government of Bombay, Karjat, India. Published with the approval of the Director of Agriculture. Received for publication August 11, 1938.

[2]Crop Botanist and Graduate Assistant respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 940.

MATERIAL AND METHODS

Two pure lines of flax, K-5-23 and M-148-5, evolved at the Cereal Breeding Station, Kundewadi, Niphad, were chosen to study the various phases of flowering. The former is a selection from the local linseed collected from the village (Kundewadi), and the latter was obtained from a bulk sample collected from Malegaon. Both the villages are in the Nasik district. M-148-5 matures a week later than K-5-23 and has a more branching and bushy habit of growth as compared to the sparser and taller habit of growth of the other strain. Both types have blue flowers of similar size. In the evening previous to the day of making the observations, 25 buds with corollas visible were labelled. About three to four plants were required to obtain the necessary number. On one day only 16 buds were available. The strain K-5-23 was studied for seven days and M-148-5 for two days only. The records of temperature and wind movement are given in Table 1.

RESULTS

FIRST OPENING

The flax flowers began to open at 7 a.m., the process of blooming either being retarded or accelerated according to the climatic condition of the day. In Table 2 are recorded data on the frequency of fully opened flowers at half hourly intervals on different days. It will be seen that on December 17, 18, and 19, 1936, almost all the flowers in K-5-23 bloomed between 9 and 10:30 a.m. These were warm days. The temperature from 9 to 11 a.m. on December 17, 18, and 19 was between 68° to 75°, 65° to 80°, and 65° to 76° F, respectively. The minimum temperatures recorded on these days was 46°, 48°, and 46° and the maximum 84°, 84°, and 85°, respectively.

The next three days on which observations were made, December 27 and 28, 1936, and January 2, 1937, were colder days. On these days the minimum and maximum temperature recorded were 39°, 36°, and 36° and 77°, 81°, and 88°, respectively. It will be seen that on these days blooming was delayed up to 10 a.m. when the temperature reached 66°, 65°, and 71°, respectively.

January 7, 1937, was a very cold day. The minimum and maximum temperatures recorded were 33° and 84°, respectively. Unfortunately, on that day only 16 flowers were available for study and of these 5 did not bloom at all. The temperature reached 64° at 10 a.m. and progressed gradually to 71°, 73°, and 77° at 11 a.m., 12 noon, and 1 p.m., respectively. Out of 11 flowers 7 opened between 1 to 1:30 p.m. Thus on colder days there was a definite retardation in the time of blooming. If more flowers had been available for observation, most probably a greater number would have been observed to bloom before 1 p.m.

So far only the behavior of strain K-5-23 has been considered. Data on the other strain, M-148-5, are available for only two days. Here again we see (Table 2) that flowering is delayed on the cold day of December 27, 1936, while it was earlier on the December 19, a warmer day.

Compared to K-5-23, it will be seen that the flowering in this strain on the corresponding days, i.e. on December 19 and 27, 1936, was

TABLE 1.—*Hourly temperatures, relative humidity, and total wind movements for the 24 hours from 8:00 a.m. to 8:00 a.m.*

Time	Dec. 17, 1936		Dec. 18, 1936		Dec. 19, 1936		Dec. 27, 1936		Dec. 28, 1936		Jan. 2, 1937		Jan. 7, 1937	
	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %	Temp. F°	Humidity %
7:00 a.m.	48°	89	50°	90	47°	90	40°	85	37°	80	37°	80	34°	84
8:00 a.m.	56°	69	55°	78	55°	74	44°	80	42°	70	43°	61	41°	65
9:00 a.m.	68°	48	65°	70	65°	65	57°	70	60°	50	55°	65	57°	40
10:00 a.m.	70°	42	72°	60	72°	64	66°	42	65°	35	71°	44	64°	38
11:00 a.m.	75°	40	80°	46	76°	50	70°	30	70°	31	80°	25	71°	28
12:00 a.m.	76°	40	81°	44	77°	52	71°	32	71°	29	82°	22	73°	26
1:00 p.m.	81°	42	82°	42	80°	47	72°	30	74°	30	85°	17	77°	21
2:00 p.m.	82°	40	83°	39	84°	43	74°	26	77°	32	86°	18	79°	21
3:00 p.m.	83°	39	84°	37	84°	31	75°	30	78°	30	87°	20	81°	20
4:00 p.m.	83°	37	82°	36	82°	30	77°	36	80°	29	86°	23	83°	26
5:00 p.m.	81°	37	80°	40	79°	27	75°	37	78°	33	84°	23	81°	30
6:00 p.m.	77°	45	75°	50	73°	41	67°	34	72°	33	78°	30	78°	25
Min. temp.	46°	—	48°	—	46°	—	39°	—	36°	—	36°	—	33°	—
Max. temp.	84°	—	84°	—	85°	—	77°	—	81°	—	88°	—	84°	—
Total wind movement in 24 hours	80		90		125		65		55		115		60	

TABLE 2.—*Time of first opening of flax flowers of two strains on various days.*

Time of full opening	Strain K 5-23							Strain M 148-5,	
	December, 1936					Jan., 1937		Dec., 1936	
	17	18	19	27	28	2	7	19	27
	Warm day	Warm day	Warm day	Cold day	Cold day	Cold day	Very cold day	Warm day	Cold day
9:01– 9:30 a.m....	8	12	11	—	—	—	—	—	—
9:31–10:00 a.m...	12	11	12	1	1	1	—	8	—
10:01–10:30 a.m...	4	—	2	7	5	9	—	3	—
10:31–11:00 a.m...	—	2	—	10	5	7	—	1	7
11:01–11:30 a.m...	—	—	—	4	6	4	1	7	3
11:31–12:00 a.m...	1	—	—	3	3	3	1	1	7
12:01–12:30 p.m...	—	—	—	—	1	—	—	—	—
12:31– 1:00 p.m...	—	—	—	—	3	—	—	—	1
1:01– 1:30 p.m...	—	—	—	—	1	—	7	—	—
1:31– 2:00 p.m...	—	—	—	—	—	—	1	—	—
2:01– 2:30 p.m...	—	—	—	—	—	—	1	—	—
Not fully open.....	—	—	—	—	—	1	5	5	7
Total..........	25	25	25	25	25	25	16	25	25

later than in the former. It appears, therefore, that strain differences, at least to a certain extent, also play a part in determining the general time of blooming.

The flowers begin to close from 4:30 p.m. onwards and continue to do so up to sunset. At this period all the flowers that have bloomed during the day are found to have closed completely.

SECOND OPENING

Data on the time at which flowers reopen for the second time are presented in Table 3. It was observed that some flowers shed their petals during the act of opening. Such flowers have been classed as "Petals shed while reopening." Besides these, there were flowers which had not opened completely at the first opening and which behaved the same at the time of the second opening. Such flowers were treated separately and are classed as "Did not reopen."

The number of flowers available next day for observation varied greatly from day to day. This was mainly due to movements of wind which caused considerable incidence of shedding of petals. Thus, on December 18, 1936, 12 flowers were available for observation out of the 25 studied the previous day. This was a calm day, the total wind movement being only *80 miles*. On the next two days the afternoons were windy (total wind movement *90 and 125 miles*) and only 2 to 3 flowers out of 25 were left with petals intact.

Due to the above reasons, only very few flowers were available for observation on some of the days. It will be seen from Table 3 that the second opening was earlier than the corresponding first opening. It

will also be noted that more flowers reopened following a colder day than a warmer day, provided there had been no interference from wind.

TABLE 3.—*Time of second opening of some of the flax flowers recorded in Table 2.*

Time of full opening	Strain K 5-23							Strain Malegaon 148-5,	
	December, 1936					Jan., 1937		Dec., 1936	
	18	19	20	28	29	3	8	20	28
8:31– 9:00 a.m.	5	2	—	—	—	—	—	—	—
9:01– 9:30 a.m.	3	—	2	—	—	—	—	—	—
9:30–10:00 a.m.	—	—	—	5	6	—	—	—	—
10:01–10:30 a.m.	—	—	—	1	—	—	1	—	7
10:31–11:00 a.m.	—	—	—	—	—	—	4	—	—
11:01–11:30 a.m.	—	—	—	—	—	—	1	—	—
11:31–12:00 a.m.	—	—	—	—	—	—	—	—	—
Did not reopen	—	—	—	—	—	1	5	4	5
Petals shed while re-opening	4	—	1	5	5	2	2	1	1
Total	12	2	3	11	11	3	13	5	13

PETAL SHEDDING

The flowers commenced to shed their petals the same day they opened. There was, however, very wide variation in the period a flower took to shed its petals after full opening. Flowers shed their petals within 2 hours after full opening while others were as late as 30 hours, i.e., after the second opening. Usually the shedding commenced after 12 noon and was in full swing 2 hours later. The process continued throughout the afternoon. Wind, as a mechanical agent, played an important part in hastening the shedding of petals.

In the majority of cases all five petals were shed simultaneously, while in some cases only a petal or two was shed at first. In certain flowers all the petals became loose, but remained hung up together for a period until they finally dropped down or dried up then and there. Some of the remaining flowers shed their petals the next morning.

DEHISCENCE OF ANTHERS

The time at which anthers burst was noted for 5 days in strain K–5–23 and for 1 day in strain M–148–5. The time of bursting of anthers and the time of full opening of each of the 25 flowers studied on various days are given in Table 4. It will be noted from the table that on warmer days anthers began to liberate pollen much earlier than on colder days. On very cold days the period was delayed still further. The behavior of strain M–148–5 on December 19, 1936 appeared to be more erratic than that of strain of K–5–23 on December 17 and 18, 1936. Apparently here also strain differences influenced the time of dehiscence of anthers.

It will also be seen from Table 4 that the anthers invariably dehisced before the flowers opened completely. In other words, dehiscence took place while the flower was half way open.

On colder days the interval between the time of anthers bursting and full blooming was lengthened as the petals made much slower movements to open out.

POLLINATION

The anthers begin to burst longitudinally. At this time the flower is usually in a semi-opened condition. In the case of late-opening buds and on colder days anthers burst in a number of cases much earlier and before the flower is in a semi-opened condition. At the time of bursting the anthers are away and in level with the twisted stigma. As the petals unfurl, the anthers move together and form a cap over the stigmatic surface. This insures self-fertilization very largely and takes place before the flower opens completely. In spite of such a mode of pollination, the average amount of vicinism in flax is 3% under Niphad conditions, according to Kadam, *et al.* (4).

DISCUSSION

From the foregoing evidence it will be seen that temperature plays an important part in either hastening or retarding the progress of anthesis in flax. The minimum temperature of the day exerts a greater influence in determining the time of the commencement and of the complete opening of a flax flower. If it is lower, anthesis is delayed; if higher, anthesis is hastened. On normal days during the flowering period flowers first begin to open at 7 o'clock in the morning and complete the process between 9:30 and 10 a.m. On colder days the two corresponding periods are 7:30 a.m. and 10 a.m. to 12 noon. On very cold days anthesis is considerably drawn out and may continue as late as mid-afternoon.

The time of commencement and of full blooming at Niphad are later than observed by the Howards at Pùsa. This is due to lower temperatures obtaining during the flowering period—December to January—at Niphad as compared to higher temperatures in February when flax is in flower at Pusa. Casual observations indicate that a more or less similar situation prevails in later maturing types at Niphad, e.g., Redwing flax of Canada, which bloom during early or mid-February.

Besides temperature, strain differences also influence anthesis to a certain extent. Differential behavior was observed between the two strains, K–5–23 and M–148–5. The latter produces a greater number of sub-branches and tertiary branching. Flower buds are larger on larger branches as compared to those produced on tertiary branches. The smaller buds are slower in their movements than larger buds so that a mixture of large and small buds in M–148–5 results in long drawn out and irregular blooming. In the case of K–5–23 there are fewer branches and sub-branches and the flower buds produced on these are more or less of similar size which results in a comparatively uniform exhibition of anthesis.

TABLE 4.—*Time of dehiscence of anthers and full opening of flowers of two strains of flax on various days.*

Bud No.	Strain K 5-23										Strain M 148-5.	
	Warm day, Dec. 17, 1936		Warm day, Dec. 18, 1936		Cold day, Dec. 28, 1936		Cold day, Jan. 2, 1937		Very cold day, Jan. 7, 1937		Warm day, Dec. 19, 1936	
	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening	Anther bursting	Full opening
	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.	A.M.
1	8:37	9:23	8:25	9:42	9:45	12:24 (P.M.)	9:11	10:45	9:45	1:15 (P.M.)	9:02	11:30
2	8:25	9:28	8:20	9:05	8:49	10:50	9:10	10:25	9:33	2:00 (P.M.)	8:30	9:35
3	8:37	10:15	8:35	9:50	9:15	10:40	9:14	10:50	9:26	1:15 (P.M.)	8:35	9:35
4	8:49	10:8	8:25	9:50	8:45	10:30	9:13	10:10	9:15	12:00	8:40	9:45
5	8:50	9:44	8:35	9:28	9:24	11:10	9:02	10:15	9:50	—*	8:50	11:15
6	8:26	9:31	8:26	9:25	8:45	10:00	9:05	10:05	10:05	—*	8:45	10:02
7	8:26	9:10	8:26	9:42	9:15	10:52	9:15	10:55	9:20	1:15 (P.M.)	8:52	11:15
8	8:27	9:22	8:27	9:27	9:11	10:30	9:18	11:45	9:51	—*	8:41	9:45
9	8:39	9:11	8:27	10:45	9:27	11:36	9:35	11:45	9:46	—*	10:10	—*
10	8:28	9:34	8:28	9:40	9:27	1:30 (P.M.)	9:05	10:15	9:37	2:30 (P.M.)	8:41	9:36
11	8:33	9:37	8:28	9:38	8:50	10:30	9:00	9:55	10:04	—*	8:51	10:45
12	8:50	10:06	8:28	9:05	9:05	10:30	9:08	10:25	9:37	1:15 (P.M.)	8:46	10:15
13	8:51	9:54	8:20	9:05	9:06	10:40	10:20	—*	9:15	11:20	8:56	11:15
14	8:35	9:30	8:20	9:30	9:22	12:31 (P.M.)	9:18	10:35	9:34	1:15 (P.M.)	8:55	11:30

15	8:29	9:45	8:27	9:05	9:21	11:25	9:33	11:15	9:40	1:15 (P.M.)	8:57	11:15
16	8:50	9:38	8:29	9:17	9:14	11:05	9:30	11:15	9:34	1:15 (P.M.)	8:52	10:07
17	8:40	9:29	8:31	9:56	9:20	11:38	9:30	11:45	—	—	9:20	—*
18	9:18	12:00	8:30	9:39	9:02	10:49	9:33	10:45	—	—	8:42	9:41
19	8:41	9:50	8:30	9:40	9:00	10:30	9:27	10:45	—	—	9:17	—*
20	8:20	9:39	8:30	9:41	9:23	11:10	9:32	10:35	—	—	9:05	12:00
21	8:25	10:16	8:30	9:27	9:26	1:00 (P.M.)	9:20	10:15	—	—	8:43	9:41
22	8:13	9:42	8:30	11:00	9:25	1:00 (P.M.)	9:20	10:25	—	—	9:00	11:15
23	8:30	9:46	8:31	9:24	9:15	11:05	9:34	11:10	—	—	9:20	—*
24	8:30	9:43	8:31	9:55	9:25	11:45	9:27	11:10	—	—	8:44	9:55
25	8:30	9:24	8:31	9:25	9:25	11:10	9:10	10:10	—	—	9:45	—*

*Did not fully open.

Irrespective of the climatic condition of the day, anthers invariably burst before the flowers fully bloom. This behavior enables emasculation of flowers for hybridization in early morning. The safest time to emasculate is between 7 and 7:30 a.m. Flowers emasculated at this period and protected from pollination have been found to set no capsules. Emasculation is done by pulling off the corolla with a swift jerk by means of forceps. The anthers are removed subsequently and pollination done 2 hours later.

SUMMARY

1. Under Niphad conditions flax flowers normally commence to open at 7 a.m. and opening is completed by 10 to 10:30 a.m. If the days are cold the process is delayed and may go on up to as late as 2:30 p.m. The minimum temperature of the day influences both time of beginning and full opening of a flower.

2. Flax flowers reopen the next day to a varying extent and the second opening is earlier than the first.

3. Petals may be shed as soon as 2 hours after full opening or may be delayed 30 hours, i.e., until after the second opening.

4. Dehiscence of anthers invariably precedes the full opening of the flowers.

5. There are indications that strain differences may also exist in the period of modal blooming in flax.

LITERATURE CITED

1. FRUWIRTH, C. Die Züchtung der landw. Pflanzenzuchtung, III, Aufl. 4 ganzlich umgearb. 1922. (Not seen in original.)
2. HOWARD, A, HOWARD, G. L. C., and KAHN, A. R. Studies in the pollination of Indian crops. I. Mem. Dept. Agr. India (Bot. Ser.), 10:195–220. 1919.
3. HOWARD, G. L. C., and KAHN, A. R. Studies in Indian oil seeds. II. Linseed. Mem. Dept. Agr. India (Bot. Ser.), 12:135–183. 1924.
4. KADAM, B. S., KULKARNI, R. K., and PATEL, S. M. Natural cross-pollination in linseed. Madras Agr. Jour. 26:3–9. 1938.
5. TAMMES, T. Die Flachsblüte. Rec. Trav. Bot. Neerland, 15:185–227. 1918. (Not seen in original.)

THE RELATION BETWEEN LEAF TISSUE PIGMENT CONCENTRATION AND YIELD IN CORN[1]

Elmer S. Miller and I. J. Johnson[2]

As pointed out by Spoehr (4),[3] the physiological processes associated with the synthesis of dry matter in plants have been investigated in detail. The application of the knowledge gained from these studies to plant breeding research should provide an opportunity to further evaluate the extent to which variations in physiological properties are associated with such factors as yielding ability. Since chlorophyll is an essential factor in the photosynthetic system, a further study of the relation between the concentration of chlorophyll and yielding ability within various strains of crop plants may furnish data which would aid in the selection of superior strains.

Sprague and Curtis (5) have studied the correlation between the amount of chlorophyll per 100 sq. cm. of leaf area and total chlorophyll per plant to the yield of shelled grain and total dry matter in corn. In general, these investigators obtained correlation coefficients that were positive, but because of the small numbers of inbred strains and crosses used several of the coefficients are too low to be statistically significant when interpreted on the basis of Fisher's (1) levels of significance for small numbers. Therefore, it seemed desirable to make a further study of these relationships with several groups of material available in the corn improvement program.

EXPERIMENTAL METHODS

In the study begun in 1936, a group of yellow endosperm crosses and their parental inbred lines were grown at the Waseca Branch Station in single row plats 10 hills long. The yields of the single crosses had been previously determined in a replicated yield trial conducted in 1934–35. Leaf tissue samples for pigment determinations were collected approximately three weeks after the silking stage. Five 1-sq. cm. areas were removed with a leaf punch from the ear leaf of five plants, placed in a small vial, and immediately frozen with "dry ice." A similar number of samples were obtained from the same leaves and preserved in acetone. The acetone-preserved and frozen samples were then stored three months in the dark at $-15°$ C. until analyzed.

During 1937 a large number of Golden Bantam single crosses were grown in replicated trials. The crosses employed in this study were selected for analysis on the basis of the chlorophyll percentage of the inbred lines made in single plat trials in 1936 and in each of two series of plats grown in 1937. From 16 inbred lines analyzed for total chlorophyll and carotenoids, four were classified as high and four as low in total chlorophyll. The difference between the high and low

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[3]Figures in parenthesis refer to "Literature Cited", p. 946.

chlorophyll inbred lines was statistically significant. Twenty-eight single crosses representing all combinations of high × high, high × low, and low × low chlorophyll inbred lines were studied for total chlorophyll and total carotenoids concentration in each of two field replications.

Pigment studies were also made on a group of 36 yellow dent inbred lines used in hybrid combinations in the corn improvement program. These yellow dent lines were grown in two field replications and leaf tissue samples from these were collected for analysis.

In all of the material sampled in 1937, five 1-sq. cm. areas were removed from the ear leaf of each of five plants and immediately frozen in a stoppered vial by "dry ice." Previous studies by Sprague and Curtis (5) showed that the chlorophyll content of the ear leaf furnished a reliable index of the amount found in the leaves of the entire plant. The Golden Bantam inbred lines were analyzed the day following collection to enable the proper selection of single crosses. The single crosses and field corn inbred lines were stored in the dark at −15° C until analyzed 4 to 5 months later.

The frozen leaf samples for pigment analysis were weighed, then triturated with sand in a mortar. After the pigments were extracted with acetone for 1 hour in a Goldfisch extractor, the acetone solution of pigments was transferred to a separatory funnel containing 25 to 30 cc of diethyl ether. The acetone in the solution was removed by several washings with water. The percentage of chlorophyll A and B and total carotenoids was determined (in ether) spectrophotometrically.

EXPERIMENTAL RESULTS

METHODS OF PRESERVING LEAF SAMPLES

Since no adequate studies had been made concerning the best method of preserving leaf tissue samples for chlorophyll determinations, samples frozen in the field as well as those preserved in acetone were analyzed for chlorophyll A and B. Because the samples for the frozen and acetone series had been collected from the same leaves, it was possible to treat the two methods of preservation on the different crosses as a series of paired comparisons. The analytical data obtained were studied by means of the analysis of variance to determine the significance of the difference between the two methods and by means of correlation coefficients to determine the relationship between the values obtained. The results of this study with 53 paired samples are presented in Table 1.

TABLE 1.—*Relation between the percentage of total chlorophyll and the ratio of chlorophyll A to B from 53 samples of frozen and acetone-preserved corn leaf tissue.*

Characters analyzed	Frozen tissue	Acetone preserved tissue	Difference	F
Percentage total chlorophyll....	0.349	0.370	0.021	9.41*
Ratio of chlorophyll A to B.....	3.88	4.15	0.27	12.11*

*Exceeds the 1% point in level of significance.

Although the differences in percentage of total chlorophyll and the ratio of chlorophyll A to B by the two methods of preservation were relatively small, the consistency of these differences among the samples gave a significant value for F. A correlation coefficient of +0.638

was obtained for total chlorophyll and +0.752 for the ratio of chlorophyll A to B by the two methods employed. Both of the coefficients exceed the 1% point in level of significance and indicate a consistant relationship between the analytical results for the two methods of preservation.

The authors selected the freezing method as being superior to the acetone method of preservation because after 90 to 150 days storage extracts of the frozen tissues spectroscopically were more like those extracts obtained from fresh tissues (extracted immediately after collection). Apparently the small difference observed in the two methods of preservation is due to oxidation of the chlorophylls. The acetone-preserved samples showed a consistently higher absorption at wave length 6700 A than the frozen samples. Recently, McKinney (3) has pointed out the possible changes occurring in leaf tissues when subjected to different methods of killing the cells. His data for tobacco indicate that freezing technic is satisfactory for killing leaf tissues.

RELATION BETWEEN CHLOROPHYLL AND CAROTENOID PIGMENTS AMONG INBRED LINES AND F_1 CROSSES

In the study of leaf pigments of sweet corn, analyses were made for total cholorophyll and total carotenoid pigments of inbred lines and their single crosses. The inbred lines and single crosses differed significantly in percentage of total chlorophyll and total carotenoids as measured by the analysis of variance from duplicate plats. This provided an opportunity to study the correlation between the percentage of total chlorophyll and total carotenoids of the inbred lines and their single crosses. A summary of these corrleation coefficients is presented in Table 2.

TABLE 2.—*Correlation between total chlorophyll and total carotenoids of parents and single crosses.*

Characters correlated	Correlation coefficients	
	Total chlorophyll	Total carotenoids
High parent and F_1 crosses	0.5745	0.3452
Low parent and F_1 crosses	0.6102	0.4895
Average of both parents and F_1 crosses	0.7032	0.4893

Level of significance for 5% point = 0.3809
Level of significance for 1% point = 0.4869

From the data in Table 2 it is evident that there is a significant correlation between total chlorophyll and total carotenoids in the inbred lines and their F_1 crosses. For total chlorophyll all of the correlation coefficients between the parents and their F_1 crosses exceed the 1% point in level of significance. For total carotenoids, the correlations between the low parent and average of both parents with the F_1 crosses exceed the 1% point, while the relation between the high parent used and the F_1 crosses was somewhat below the 5% point in level of significance. These results indicate the extent to which, under the conditions of the experiment, total chlorophyll and carotenoid development were dependent upon inheritance.

Evidence was obtained also that the percentage of total chlorophyll in the F_1 crosses consistently exceeded the average of the two parents, indicating a possible heterosis for the chlorophyll pigments. The average percentage of total chlorophyll and total carotenoid pigments of the inbred lines and their single crosses is given in Table 3.

TABLE 3.—*Average percentage of total chlorophyll and total carotenoid pigments of inbred lines and single crosses of Golden Bantam sweet corn.*

Chlorophyll or carotenoid pigments of inbred parents	No. of crosses	% chlorophyll		% carotene	
		F_1 cross	Ave. of parents	F_1 cross	Ave. of parents
High×High........	6	0.431	0.375	0.0680	0.0379
High×Low........	16	0.379	0.331	0.0567	0.0337
Low×Low.........	6	0.335	0.288	0.0542	0.0293

RELATION BETWEEN TOTAL CHLOROPHYLL CONCENTRATION AND YIELDS

Since the relationship between chlorophyll concentration and yield is of importance to both the plant breeder and plant physiologist, a study was undertaken with several groups of material to determine the extent to which variation in total chlorophyll was coincident with variation in yield. In this study a group of single crosses in dent corn, a group of single crosses of Golden Bantam sweet corn, and two groups of inbred lines were investigated. A summary of the data obtained, together with a study of the relation between total chlorophyll and total carotenoid pigments, is given in Table 4.

From the results presented in Table 4 it becomes evident that there is very little association between total chlorophyll (green weight basis) and yielding ability of corn. These data are in agreement with those reported by Jenkins (2) who obtained correlation coefficients of −0.07 and −0.11 between chlorophyll grade (concentration) of parents and yield of crosses for 1926 and 1927, respectively. Likewise, he obtained a correlation coefficient of −0.21 between chlorophyll grade and yield of inbred lines.

The evidence presented in Table 4 does not confirm the data reported by Sprague and Curtis (5), who obtained the following correlation coefficients: For the inbred lines (12 strains) $+.55\pm.14$ between shelled grain per plant and chlorophyll per 100 sq. cm. of leaf blade and $.46\pm.15$ for chlorophyll per plant and total yield; for F_1 crosses (18 strains) $+.25\pm15$ between shelled grain per plant and chlorophyll per 100 sq. cm. of leaf blade and $+.36\pm14$ between chlorophyll content and yield of shelled corn.

In the field corn single crosses used in this study, 43 hybrids varied from 0.287 to 0.475% chlorophyll and the yields from these same crosses varied from 87 to 127% of the check varieties employed, indicating widely different values for both total chlorophyll and yield. A correlation coefficient of −0.328 does not approach the 5% point in level of significance and indicates that variations in yield are not related to variations in total chlorophyll. The writers wish to point out

that these yields are for the average of 1934 and 1935 and that the chlorophyll data is for a single plat grown in 1936.

TABLE 4.—*Correlation between chlorophyll and yield within single crosses of inbred lines of corn and between total chlorophyll and total carotenoid pigments.*

Characters correlated	Material studied	Year	N	Correlation coefficient
In Single Crosses				
Per cent total chlorophyll and per cent total carotenoids	Sweet corn	1937	28	.754†
Per cent total chlorophyll and per cent total carotenoids	Field corn	1936	43	.337*
Per cent total chlorophyll and yield	Sweet corn	1937	28	−.065
Per cent total chlorophyll and yield	Field corn	1936	35	−.328
In Inbred Lines				
Per cent total chlorophyll and per cent total carotenoids	Sweet corn	1937	16	.838†
Per cent total chlorophyll and per cent total carotenoids	Field corn	1937	36	.853†
Per cent total chlorophyll and yield	Sweet corn	1937	16	.105
Per cent total chlorophyll and yield	Field corn	1937	36	.147
Per cent total chlorophyll and top cross yield	Field corn	1937	36	−.203
Mgm. total chlorophyll in ear leaf and yield	Field corn	1937	36	.106
Mgm. total chlorophyll per sq. cm. leaf and leaf area	Field corn	1937	36	−.195
Per cent total chlorophyll 1936 and 1937	Sweet corn	——	16	.642†

*Exceeds the 5% point in level of significance.
†Exceeds the 1% point in level of significance.

In a group of Golden Bantam single crosses, total chlorophyll determinations and yield were made in the same series of plats. In this study the crosses showed significant variation in percentage of chlorophyll concentration, and the single crosses approached the 5% point in level of significance for variation in yield. In this group the correlation coefficient was −0.065.

In the studies involving total chlorophyll and yield with inbred lines of sweet corn, a correlation coefficient of +0.105 was obtained with a group of 16 inbred lines, whereas a coefficient of +0.147 was found for 36 inbred lines of field corn. Neither one of these coefficients is significant. Since the above coefficients are between total chlorophyll and yield, a study was made on 36 lines of field corn to determine the relationship between the mgm. of chlorophyll in the ear leaf and yield. The coefficient obtained was +0.106 and likewise is not significant. Finally, a study was made to determine the relation between total chlorophyll of 36 inbred lines and their combining ability as measured by top cross yields conducted in four replicated trials. The coefficient obtained, −.203, is also below the 5% point in level of significance.

Since none of the correlation coefficients between chlorophyll and yield are statistically significant in any of the groups of material studied, it would appear that variations in chlorophyll concentration

do not have an important effect on yield in corn. These results would therefore suggest that the quantities of chlorophyll found in normal green corn plants are more than sufficient and that chlorophyll is not a limiting factor in the development of yield in corn. In fact, the quantities of chlorophyll may be in excess of the normal needs since variegated plants having nearly 50% of the leaf tissue devoid of chlorophyll are seemingly nearly as vigorous as normal green plants.

In all groups of material studied, a significant correlation was obtained between the percentage of total chlorophyll and the percentage of total carotenoids. Evidently those physiological processes that result in the formation of chlorophyll pigments are closely related to those which result in the development of carotenoid pigments.

SUMMARY

1. A comparison was made between the freezing and acetone methods for preserving leaf tissues for pigment analysis. Spectrophotometrically, the least amount of decomposition occurred in the frozen series, although the discrepancy between the two methods is very slight.

2. Evidence was obtained that a very marked relationship exists between total chlorophyll and total carotenoids in the parental inbred lines and in their F_1 crosses.

3. Analytical data show that the percentage of total chlorophyll in the F_1 crosses exceeded the average of the two parents, indicating possible heterosis for the chlorophyll pigments.

4. In the study with several groups of material to determine the relation between total chlorophyll concentration in the leaf tissue and yield in corn, it was found that the correlation coefficients were less than required to attain the 5% point in level of significance.

5. A highly significant positive correlation was obtained between the percentage of total chlorophyll and total carotenoids in corn leaf tissue.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 6, 1936.
2. JENKINS, MERLE T. Correlation studies with inbred and crossbred strains of Maize. Jour. Agr. Res., 39:677–721. 1929.
3. MCKINNEY, G. Some absorption spectra of leaf extracts. Plant Phys., 13:123–140. 1938.
4. SPOEHR, H. A. Photosynthesis. New York: Chem. Catalog Co. 1926.
5. SPRAGUE, HOWARD B., and CURTIS, NORMAN. Chlorophyll content as an index of the productive capacity of selfed lines of corn and their hybrids. Jour. Amer. Soc. Agron., 25:709–724. 1933.

UNBALANCED ARRANGEMENTS OF PLATS IN LATIN SQUARES[1]

S. C. SALMON[2]

A STRICT use of random arrangement of plats in Latin squares usually results in an unbalanced distribution of the plats of one or more of the treatments. A striking example are diagonal squares in which all plats of a treatment fall in a straight line on one of the principal diagonals, those of the other treatments falling on secondary diagonals or in various ways. In this paper the term diagonal square is used to designate those in which all plats of a treatment fall on one of the principal diagonals irrespective of the arrangement of the plats of the remaining treatments.

Practical agronomists and statisticians will no doubt generally agree that such arrangements are unsatisfactory. Tedin[3] and Fisher[4] have indicated or implied agreement with this viewpoint. Observations suggest that the objections to them would be almost, though perhaps not quite, so great as having all plats of a given variety or treatment in a single row or column. The use of local control or the usual row and column restrictions in otherwise random Latin squares were devised in part to avoid the latter contingency. The frequency with which diagonal squares occur would therefore seem to be of some consequence.

Fig. 1 is a 4×4 Latin square with the usual row and column re-

	1	2	3	4
1	A	C	D	B
2	C	A	B	D
3	B	D	A	C
4	D	B	C	A

FIG. 1.—A diagonal Latin square.

strictions. A, B, C, and D are varieties or treatments to be compared. All four plats of variety or treatment A fall on one of the principal

[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication August 24, 1938.

[2]Principal Agronomist.

[3]TEDIN, OLAF. The influence of systematic plot arrangement upon the estimate of error in field experiments. Jour. Agr. Sci., 21:191–208. 1931.

[4]FISHER, R. A. The Design of Experiments. London: Oliver and Boyd. 1935. (Pages 85 to 90.)

diagonals. The question to be answered is how frequently may such an arrangement, with respect to A alone, be expected as a result of chance.

Considering first row 1, it will be apparent that in order to have the particular diagonal square illustrated in Fig. 1, A must fall in column 1. Since there are four plats in the row the probabilities of its doing so are obviously one-fourth. In row 2, A is excluded from column 1, because otherwise there would be two plats of A in that column. Since it may fall in any one of the three plats that are left, the probability of its falling in column 2 is one-third. In row 3, A is excluded from columns 1 and 2, there are two left, and consequently the probability of its falling in column 3 is one-half. With the positions of A thus determined for the first, second, and third rows, the fourth plat must fall in column 4 of row 4. The probability is, therefore, certainty or one.

The probabilities of all four plats of A falling on the principal diagonal represented in figure 1 is $\frac{1}{4} \cdot \frac{1}{3} \cdot \frac{1}{2} \cdot \frac{1}{} = \frac{1}{24}$. That is, all four plats of the A variety or treatment would be expected to fall as indicated once in 24 Latin squares. But there are two diagonals and four varieties or treatments. Hence the probability of all four plats of any one variety or treatment falling on one or the other of the two principal diagonals is $\frac{1}{24} \cdot \frac{2}{} \cdot \frac{4}{} = \frac{1}{3}$. If the result is surprising to those who have not considered the matter, it can easily be verified by empirical trials, or in some cases by observing Latin square experiments actually in use.

It will now be instructive to determine the probability of a similar occurrence in a 4×4 Latin square without the row and column restrictions, i.e., one in which all plats are distributed at random with no restrictions whatever. In this case the possibility of all plats occurring in any row or column as well as on the diagonals must be considered.

In a manner similar to that above, it can be shown that the probability of all four plats of A falling in a designated row, column, or principal diagonal is $\frac{4}{16} \cdot \frac{3}{15} \cdot \frac{2}{14} \cdot \frac{1}{13} = \frac{1}{1820}$; and the probability of all four plats of any variety or treatment falling in a like manner, i.e., the probability of getting four plats of any variety or treatment in a straight line whether this be in rows, columns, or diagonals, is

$$\frac{1}{1820} \cdot \frac{4\,(4+4+2)}{} = \frac{40}{1820} = \text{approximately } \frac{1}{45}.$$

This means that in a 4×4 Latin square the chances of getting all four plats of any variety or treatment in a striaght line are 15 times as great with restricted as with unrestricted random distribution. It thus appears that the imposition of row and column restrictions on otherwise random Latin squares not only fails to accomplish one of the purposes for which they were intended but actually increases to a very considerable degree the tendency toward unbalanced distributions in so far as these are measured by the frequency of those in which all plats of a variable occur in a straight line.

There are, of course, other unbalanced and undesirable arrangements. Thus, two plats may fall on a principal diagonal and the remaining plats next to the principal diagonal. In a restricted Latin square the probabability of such an occurrence is twice that for all plats on a diagonal .Or all plats but one, or a majority of all plats, may fall on or on one side of a diagonal.

The probability of having all plats in a straight line decreases as the size of the Latin squares increases, but the proportion of cases in which such an arrangement is obtained in restricted as compared with unrestricted random arrangements increases as the size of the Latin squares increases. Thus, in a 5×5 Latin square the respective probabilities for restricted and unrestricted arrangements are approximately 1/12 and 1/886. The corresponding probabilities for a 6×6 Latin square are 1/60 and 1/23188. Hence, the ratios in restricted arrangements to those in unrestricted arrangements are approximately 15 to 1, 74 to 1, and 386 to 1 in 4×4, 5×5, and 6×6 Latin squares, respectively. A critical study of other unbalanced arrangements has not been made.

The undesirable effects of unbalanced arrangements are particularly serious in experiments in which permanent plats are required, such as with alfalfa or grass, fruit or forest trees, and certain soil experiments. In these an unbalanced arrangement will introduce systematic errors which will persist during the life of the experiment. It should require no extensive discussion to prove that dependence on restricted random arrangements in such experiments is likely to lead to real and serious errors.

The above is presented not in support of unrestricted random arrangements, but merely to point out that some of the supposed advantages of restricted random arrangements are not realized in practice. Student[5] recently has presented what appear to be convincing arguments for balanced systematic arrangement of plats. Among other things he emphasizes that improvement in the estimate of random error brought about by the substitution of a restricted random arrangement for balanced systematic arrangements is secured only at the expense of the accuracy of the experiment itself. The facts presented herein would seem to support that point of view.

Certainly agronomists are or should be more concerned with the accuracy and reliability of an experiment than with the accuracy of the estimate of random error. Perhaps it is worth while to remember that, whereas the theoretical arguments for randomization have been developed on the assumption of large numbers, i.e., large numbers of plats or of experiments repeated a large number of times, the agronomist often finds himself obliged to base conclusions on specific experiments in which each variable is repeated only a very small number of times. This means not only that the results of an experiment are subject to some uncertainty but also that the estimate of random error is only an approximation. Indeed it is doubtful whether a statistically significant difference between estimates of error for restricted random arrangements as compared with systematic arrangements can

[5]Student. Comparison between balanced and random arrangements of field plots. Biometrika, 29:363–379. 1938.

be demonstrated for most field experiments. Also field experiments are necessarily of limited duration and they are not repeated on every farm. Often the utilization of their results depends on economic factors which also vary from time to time and from place to place. The net result is that any practical deductions derived from such experiments are subject to rather large errors of personal judgment. A difference in experimental results so small as to bring into question the reliability of the estimate of random error depending on plat arrangement is not likely to be of any importance at all. Why then be too much concerned about the estimate of random error? It is important, however, to know that all possible precautions have been taken to assure reliable experimental results.

CARBOHYDRATES OF THE COTTON PLANT UNDER DIFFERENT SEASONAL CONDITIONS AND FERTILIZER TREATMENT[1]

D. R. Ergle, L. E. Hessler, and J. E. Adams[2]

SEVERAL workers in the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, have studied the effects of fertilizers on the composition of the cotton plant (2, 3, 4, 6),[3] as a part of a broad program for the investigation of fertility factors associated with the occurrence of cotton root-rot. It has been found in field studies on soils of the Wilson series (5) that nitrogen and fertilizers having a high nitrogen content decrease the number of cotton plants killed by the fungus *Phymatotrichum omnivorum* (Shear) Duggar, while phosphate and fertilizers having a high phosphoric acid content increase the mortality. Results of studies of the carbohydrate content of the tops and roots of cotton plants grown on Wilson clay loam in Texas have been given (3). The concentration of total sugars in the roots was greater than in the tops for the growth period as a whole. The diose sugars were greater than the monose sugars in the roots. During the latter stages of boll formation the monose sugars were greater than the diose sugars in the tops. Total sugars decreased in concentration in the plant tops between the seedling stage and square formation but increased during boll formation.

Complete fertilizers produced plants with a higher level of soluble and insoluble carbohydrates in tops and roots in the latter stages of plant development. Nitrogen alone had but little effect, but phosphorus alone produced plants containing more soluble and insoluble carbohydrates in the tops. The greater carbohydrate content of the plants correlated with larger plant growth and larger yields of cotton. Fertilizer mixtures that produced plants with the greatest total carbohydrate content were the mixtures that produced largest plant growth and greatest yields.

PLAN OF EXPERIMENT

The plat arrangement, sampling technic, and methods of analysis used in previous studies (3) were followed in 1936. One series of plats was located on Wilson fine sandy loam, in Hunt County, and the other on Houston black clay, in Travis County, Texas. The Houston soils, comprising about 80% of the Blackland prairie section, are calcareous, while the normal Wilson soils are non-calcareous in the upper layers (1).

Composite samples of whole cotton plants (tops and roots) were obtained from field plats[4] used to determine the effect of fertilizer on the maturity and yield of

[1]Contribution from the Division of Soil Fertility Investigations, Bureau o Plant Industry, U. S. Dept. of Agriculture. Received for publication August 25, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 959.

[4]Acknowledgment is made to Messrs. H. V. Jordan, J. H. Hunter, P. M. Jenkins, and H. A. Nelson for the care of the plats and assistance in the collection of the samples.

cotton and the incidence of root-rot. The fertilizers used were as follows: 15-0-0, 9-3-3, 0-15-0, and 3-9-3.[5] Unfertilized plats served as checks. The fertilizer was applied at the rate of 900 pounds per acre simultaneously with the planting of the experiment to cotton.

The Wilson fine sandy loam area, designated as field C, was under drought conditions from the latter part of July to the end of the season. Premature opening of some bolls made sampling objectionable after August 11. In contrast, field D, a Houston black clay soil, received normal rainfall; however, sampling was discontinued August 10.

Records were made at weekly intervals of the morphological changes in the plants of both fields. These data have been reported in detail (5).

Approximate dates pertinent to this work are as follows:

Observations	Field C	Field D
	Wilson soil	Houston soil
Cotton up to a stand	May 4	Apr. 28
Seedling stage	June 16	June 2
Squares appearing	June 16	June 2
Bolls appearing	July 7	June 29
Light boll set	July 13	July 13
Heavy boll set	July 27	July 27
Bolls opening	Aug. 11	Aug. 3
Cotton picked	Aug. 19	Aug. 27

RESULTS

The data from the Wilson fine sandy loam (field C) are given as Table 1 and those for the Houston black clay (field D) as Table 2. These are on the basis of green material.

The effects of fertilizer treatment on plant composition as found for top and root parts (3) are reduced when the whole cotton plant is used for analysis. There is indicated, however, some fertilizer effect on plants from the Wilson soil and, to a less extent, on those from the Houston. The whole plant is a farily good indicator of the variations in carbohydrate concentration of cotton plants at different growth periods.

Seasonal changes in concentrations of carbohydrates for plants grown in unfertilized plats on Houston and Wilson soils are illustrated graphically in Fig. 1. The similarity of the two sets of graphs with respect to the indicated stages of development suggest that certain changes are inherent in the plant and that the influence of the soil type is not paramount. Even the effects of fertilizers are not sufficient to alter materially the trends in concentrations during certain morphological changes. The concentration levels may be influenced, but the direction of change will likely remain unaffected. In general the results from the unfertilized plants, as illustrated in Fig. 1, as well as those from the fertilized plants in Tables 1 and 2, show that the appearance of squares is attended by decreased concentrations of

[5]Fertilizer ratios are given in the order N-P_2O_5-K_2O. One-half of the nitrogen was derived from sulfate of ammonia and one-half from nitrate of soda; the phosphoric acid was from 18% superphosphate; and the potash from sulfate of potash.

TABLE 1.—*Carbohydrates of cotton plants grown on Wilson fine sandy loam, field C, Caddo Mills, Texas, as influenced by fertilizer treatment and stage of growth, 1936.**

Date, 1936	Mono-saccha-rides %	Disac-charides %	Total sugars %	Poly-saccha-rides %	Total carbo-hy-drates %	Weight per plant, grams	Mois-ture green material %
			Fertilizer 0–15–0				
May 19	0.37	0.09	0.46	2.33	2.79	2.53	85.3
June 2	0.32	0.33	0.65	2.75	3.40	9.42	78.6
June 9	0.42	0.55	0.97	3.13	4.10	17.50	78.8
June 16	0.60	0.93	1.53	4.42	5.95	24.50	73.9
June 23	0.68	0.78	1.46	4.39	5.85	38.00	73.5
June 30	—	—	—	—	—	51.10	70.9
July 14	1.11	0.95	2.06	5.07	7.13	75.70	73.7
July 28	1.20	1.23	2.43	7.48	9.91	108.00	66.8
Aug. 11	0.68	1.02	1.70	10.19	11.89	184.00	51.6
Average	0.67	0.74	1.41	4.97	6.38	56.75	72.5
			Fertilizer 3–9–3				
May 19	0.34	0.20	0.54	2.57	3.11	2.57	84.3
June 2	0.32	0.32	0.64	2.60	3.24	10.20	81.2
June 9	0.44	0.60	1.04	3.36	4.40	18.90	79.1
June 16	0.59	0.82	1.41	3.89	5.30	25.30	76.4
June 23	0.67	0.79	1.46	4.42	5.88	41.80	73.4
June 30	0.73	0.83	1.56	5.35	6.91	55.00	70.9
July 14	0.94	1.00	1.94	4.95	6.89	96.80	72.0
July 28	0.95	1.00	1.95	6.15	8.10	125.00	67.5
Aug. 11	0.74	1.08	1.82	9.52	11.34	185.00	53.3
Average	0.64	0.74	1.37	4.76	6.13	62.29	73.1
			Fertilizer 9–3–3				
May 19	0.32	0.19	0.51	3.02	3.53	1.97	83.1
June 2	0.35	0.28	0.63	3.54	4.17	5.97	77.8
June 9	0.47	0.53	1.00	3.39	4.39	12.10	79.2
June 16	0.62	0.91	1.53	4.04	5.57	20.30	74.9
June 23	0.60	0.73	1.33	4.12	5.45	33.30	75.1
June 30	0.69	1.01	1.70	5.29	6.99	52.50	71.9
July 14	0.89	0.95	1.84	4.64	6.48	83.20	73.3
July 28	1.17	1.14	2.31	6.92	9.23	129.00	67.5
Aug. 11	0.93	0.89	1.82	9.43	11.25	192.00	55.5
Average	0.67	0.74	1.41	4.93	6.34	58.93	73.1
			Fertilizer 15–0–0				
May 19	0.28	0.25	0.53	3.30	3.83	1.61	82.6
June 2	0.33	0.34	0.67	3.13	3.80	2.75	77.2
June 9	0.44	0.67	1.11	3.86	4.97	5.04	76.8
June 16	0.53	0.74	1.27	4.98	6.25	9.30	74.3
June 23	0.49	0.74	1.23	4.47	5.70	17.00	74.0
June 30	0.53	0.68	1.21	4.91	6.12	29.40	74.3
July 14	0.64	0.75	1.39	4.09	5.48	48.40	73.6
July 28	1.06	1.23	2.29	7.38	9.67	83.30	65.8
Aug. 11	0.62	1.14	1.76	10.36	12.12	195.00	55.1
Average	0.55	0.73	1.27	5.16	6.44	43.53	72.6

*All data expressed on green weight basis.

TABLE 1.—*Concluded.*

Date, 1936	Mono-saccha-rides %	Disac-charides %	Total sugars %	Poly-saccha-rides %	Total carbo-hy-drates %	Weight per plant, grams	Mois-ture green material %
			No fertilizer				
May 19	0.37	0.30	0.67	3.91	4.58	1.78	82.0
June 2	0.34	0.35	0.69	3.13	3.82	3.08	77.6
June 9	0.40	0.64	1.04	3.78	4.82	6.70	78.4
June 16	0.50	0.91	1.41	4.85	6.26	10.80	72.8
June 23	0.46	0.72	1.18	4.39	5.57	13.40	73.7
June 30	0.58	0.87	1.45	5.38	6.83	27.10	70.9
July 14	0.64	0.74	1.38	4.58	5.96	39.40	74.3
July 28	1.06	1.21	2.27	7.28	9.55	53.00	68.4
Aug. 11	0.72	1.18	1.90	10.20	12.10	196.00	57.2
Average	0.56	0.77	1.33	5.28	6.61	39.03	72.8

TABLE 2.—*Carbohydrates of cotton plants grown on Houston black clay soil (field D), Pflugerville, Texas, as influenced by fertilizer treatment and stage of growth, 1936.**

Date, 1936	Mono-saccha-rides %	Disac-charides %	Total sugars %	Poly-saccha-rides %	Total car-bohy-drates %	Weight per plant, grams	Mois-ture green material %
			Fertilizer 0-15-0				
May 4	0.68	0.19	0.87	3.03	3.90	1.30	83.4
May 11	0.39	0.10	0.49	3.41	3.90	2.50	84.7
May 18	0.45	0.19	0.64	—	—	5.10	81.9
June 1	—	—	0.75	5.14	5.89	8.76	76.1
June 8	0.43	0.09	0.52	3.17	3.69	17.10	78.9
June 15	0.65	0.31	0.96	3.88	4.84	31.40	77.3
June 29	0.74	0.17	0.91	4.58	5.49	64.30	73.1
July 13	0.32	0.31	0.63	5.07	5.70	137.00	75.0
July 27	0.83	0.29	1.12	6.47	7.59	212.00	72.0
Aug. 10	1.14	0.54	1.68	8.03	9.71	197.00	65.4
Average	0.63	0.24	0.86	4.75	5.63	67.65	76.8
			Fertilizer 3-9-3				
May 4	0.54	0.35	0.89	3.39	4.28	1.31	81.8
May 11	0.38	0.12	0.50	3.62	4.12	2.70	83.9
May 18	0.36	0.25	0.61	—	—	5.38	82.5
June 1	0.57	0.11	0.68	4.53	5.21	9.04	79.0
June 8	0.29	0.28	0.57	2.93	3.50	20.80	80.6
June 15	0.57	0.36	0.93	3.85	4.78	38.00	77.2
June 29	0.70	0.33	1.03	4.04	5.07	96.30	73.8
July 13	0.29	0.24	0.53	4.51	5.04	203.00	72.8
July 27	0.70	0.35	1.05	5.28	6.33	303.00	72.5
Aug. 10	1.07	0.88	1.95	8.23	10.18	303.00	62.6
Average	0.55	0.33	0.87	4.49	5.39	98.26	76.7

*All data presented on green weight basis.

TABLE 2.—*Concluded.*

Date, 1936	Mono-saccha-rides %	Disac-charides %	Total sugars %	Poly-saccha-rides %	Total car-bohy-drates %	Weight per plant, grams	Mois-ture green material %
			Fertilizer 9–3–3				
May 4	0.54	0.44	0.98	3.21	4.19	1.30	81.1
May 11	0.40	0.11	0.51	3.85	4.36	2.38	82.5
May 18	0.36	0.31	0.67	—	—	4.61	81.3
June 1	0.61	0.22	0.83	5.80	6.63	6.83	76.1
June 8	0.46	0.00	0.45	2.97	3.42	14.40	80.3
June 15	0.71	0.17	0.88	3.67	4.55	25.20	77.3
June 29	0.61	0.26	0.87	4.24	5.11	86.20	73.6
July 13	0.24	0.30	0.54	4.14	4.68	167.00	74.7
July 27	0.59	0.54	1.13	4.73	5.86	280.00	73.5
Aug. 10	0.92	0.90	1.82	8.22	10.04	272.00	63.0
Average	0.54	0.33	0.87	4.54	5.43	85.99	76.3
			Fertilizer 15–0–0				
May 4	0.46	0.41	0.87	3.20	4.07	1.27	82.0
May 11	0.35	0.23	0.58	4.00	4.58	2.20	82.0
May 18	0.36	0.32	0.68	—	—	4.33	80.0
June 1	0.63	0.22	0.85	5.72	6.57	6.46	75.4
June 8	0.30	0.24	0.54	3.20	3.74	11.30	78.6
June 15	0.35	0.52	0.87	3.88	4.75	25.40	77.8
June 29	0.49	0.40	0.89	3.93	4.82	54.90	74.7
July 13	0.20	0.30	0.50	3.87	4.37	140.00	75.8
July 27	0.59	0.39	0.98	4.58	5.56	413.00	73.0
Aug. 10	1.01	0.83	1.84	8.15	9.99	193.00	63.3
Average	0.47	0.39	0.86	4.50	5.38	85.19	76.3
			No fertilizer				
May 4	0.75	0.07	0.82	3.50	4.32	1.26	81.4
May 11	0.25	0.23	0.48	4.07	4.55	2.32	82.3
May 18	0.30	0.36	0.66	—	—	4.75	81.6
June 1	0.63	0.18	0.81	5.47	6.28	7.42	76.2
June 8	0.25	0.34	0.59	3.42	4.01	12.70	77.9
June 15	0.68	0.13	0.81	4.14	4.95	20.50	76.2
June 29	—	—	—	—	—	72.00	74.2
July 13	0.23	0.38	0.61	4.62	5.23	140.00	74.7
July 27	1.00	0.12	1.12	6.94	8.06	277.00	72.0
Aug. 10	0.98	0.80	1.78	8.22	10.00	227.00	64.1
Average	0.56	0.29	0.85	5.05	5.93	76.50	76.1

carbohydrates. This decrease is followed shortly by a general, and sometimes a sudden, increase in carbohydrates in the plants as the cotton bolls become larger and more succulent. Boll maturity is generally characterized by a very sharp rise in concentration of carbohydrates, particularly polysaccharides.

The general level of carbohydrates in plants from the Wilson soil for all treatments was higher than that in plants grown on the Houston soil. The data show that the disaccharides, regardless of treatment, were responsible for the greater part of this difference. The

average concentration of disaccharides in unfertilized plants from the Wilson soil was slightly greater than 2½ times that found in corresponding plants from the Houston soil. The difference in water content of plants from the two soils was of sufficient magnitude to exert some influence on the carbohydrate metabolism. On an average, the plants from most of the plats, both fertilized and unfertilized, on the Wilson soil contained about 4% less water than did those from plats on the Houston soil.

The monosaccharide and disaccharide contents of cotton plants grown on the Wilson soil were affected by fertilizer treatment. The fertilizer effect was more apparent on the monosaccharides than on the disaccharides. All of the fertilizer treatments, except 15-0-0, had some influence. The fact that all other treatments contained phosphorus may be significant. Three treatments used on the Wilson soil are presented in Fig. 2C, which shows the effect of fertilizers on the monosaccharides at successive stages of growth. The graph shows (a) normal changes in cotton as represented by the unfertilized check, (b) the effect of 0-15-0 fertilizer, and (c) the lack of effect of 15-0-0 fertilizer. The increased concentrations from the 0-15-0 treatment occurred during the fruiting period of the cotton plant, corresponding to the dates June 12 to July 28, inclusive. The sample of June 30 is missing for the 0-15-0 series, but the data for the 3-9-3 plat (Table 1) substantiate the trend of the 0-15-0 data as given. No consistent fertilizer effect was indicated for these fractions in plants grown on the Houston soil. The 0-15-0 fertilizer, however, produced a generally higher concentration of monosaccharides than the 15-0-0, while the converse is true for the disaccharides.

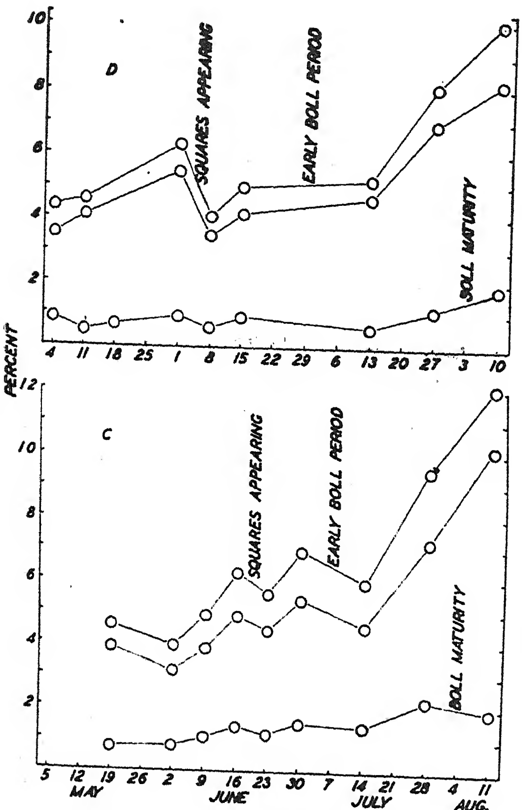

FIG. 1.—Seasonal changes in carbohydrates of cotton plants grown on Wilson fine sandy loam (C) and Houston black clay (D). Reading upward the graphs represent total sugar, polysaccharide, and total carbohydrate content, respectively.

The storage carbohydrates, represented by the polysaccharides appeared to be slightly influenced by fertilizers, but the effect was limited to the 15–0–0 and 0–15–0 ratios. Similar trends were noted in the results from plants grown on both soil types. The data from plants grown on the Houston soil indicate the fertilizer effect better. In Fig. 2D are graphs which compare the effects of treatments 15–0–0 and 0–15–0 on the polysaccharide content of plants grown on Houston soil. As compared with the "no treatment" plat, nitrogen (15–0–0) tended to show a concentration of storage carbohydrates equal to that of unfertilized plants during the early part of the season, while during the latter part a lower concentration was indicated. Phosphorus (0–15–0), on the other hand, caused less storage early in the season, but induced an equal or a greater reserve than that of unfertilized plants late in the season.

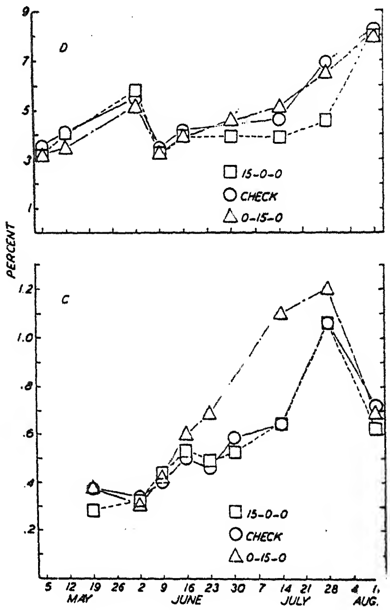

FIG. 2.—Seasonal changes in monosaccharide content of cotton plants grown on Wilson fine sandy loam (C) and polysaccharide content of plants produced on Houston black clay (D) under different fertilizer treatments.

These concentration effects from ratios 15–0–0 and 0–15–0 appeared to be correlated with plant growth, using plant weight as an index of growth. On the Houston soil, from May 4 to June 8, plant growth in the 0–15–0 plats was superior to that on the untreated and 15–0–0 plats. During this same period, the storage of carbohydrates in plants from the 0–15–0 plats was lower than that in plants from the untreated and 15–0–0 plats. Later in the season, June 29 to August 10, the average plant weight on the 15–0–0 plats was greater than that on the untreated and 0–15–0 plats, and during that time storage of carbohydrates in plants from the 15–0–0 plats was consistently lower than that of unfertilized plants and those receiving phosphorus (0–15–0). A similar correlation is found in the data from the Wilson soil. The corresponding periods for comparison were May 19 to June 16 and June 23 to August 11.

DISCUSSION

The data given here on the effects of fertilizers on monosaccharides in cotton plants grown on a Wilson soil substantiate those reported previously (3) for Wilson clay loam. The failure of this carbohydrate fraction to respond to the fertilization of plants on the Houston soil may be connected in some way with the observed difference in the

response of the two soils to fertilizers. It has been noted (5) that soils of the Wilson series give the best response to fertilizer ratios in which the amount of phosphate exceeds that of nitrogen, while the converse seems to be better adapted for Houston black clay. These differences have been obtained where the rate of application was 600 to 900 pounds per acre. The results from associated studies on the electrodialyzable components of cotton plants (6) from the same plats from which plants were selected for the carbohydrate work throw some light on the problem. These data show that the total phosphorus was higher in plants from untreated plats on the Houston soil than in those from corresponding plats on the Wilson soil. The addition of equal amounts of phosphorus to the two soils produced a higher concentration of total phosphorus in plants from the Wilson soil in every case.

The decrease in polysaccharide content with a corresponding increase in plant weight, as noted for treatments 15–0–0 and 0–15–0, might be looked upon as a plant effect and not a direct fertilizer effect. The fertilizer is indirectly concerned, of course, in that it is responsible for the increase in plant weight. There is evidence, however, which favors a direct effect on concentration of polysaccharides in the plant from the addition of nitrogen and phosphorus to the soil. It has been observed by many workers that phosphate fertilizers induce earlier maturity in cotton, while a nitrogenous fertilizer tends to prolong the vegetative condition. It is reasonable to assume that a plant which develops faster than another during a certain period will store a smaller amount of carbohydrates than the less vigorous plant.

The use of the whole cotton plant for studying the effects of fertilizers on its carbohydrate composition at successive stages of growth is somewhat less effective than the use of tops and roots separately. While the plant is small and in the formative stage, the whole plant seems to be satisfactory. When the plant has developed and formed squares and bolls and the cotton approaches maturity, it is advantageous to consider the composition of the plant parts to ascertain the effect of soil treatments on plant composition.

SUMMARY

Similar seasonal changes in carbohydrate concentrations were noted for cotton plants grown on Wilson fine sandy loam and Houston black clay soils in Texas. The level of carbohydrates was greater in plants from the Wilson soil than those from the Houston. Drought conditions on the Wilson soil probably affected this level.

The monosaccharide, disaccharide, and polysaccharide contents of plants from the Wilson soil were affected by fertilizers, while only the polysaccharides in plants from the Houston soil seemed to be definitely influenced. A correlation of fertilizer treatment and plant growth was also noted for plants from both soils.

Under the conditions of the experiment it was found that whole plants do not reflect the effect of fertilizer treatment as well as root and aerial segregates studied previously.

LITERATURE CITED

1. CARTER, W. T. The soils of Texas. Tex. Agr. Exp. Sta. Bul. 431. 1931.
2. COLLINS, EMERSON R., and RIGLER, NEIL E. Effect of fertilizers on some nitrogenous and other constituents of the cotton plant as separated by electrodialysis at different stages of growth. Soil Science, 44:217–229. 1937.
3. ERGLE, D. R. Carbohydrate content of cotton plants at different growth periods and the influence of fertilizers. Jour. Amer. Soc. Agron., 28:775–786. 1936.
4. HESSLER, L. E., ERGLE, D. R., RIGLER, N. E., and ADAMS, J. E. Composition of bark and inner part of roots of the cotton plant. In Press.
5. JORDAN, H. V., HUNTER, J. H., and ADAMS, J. E. The relation of fertilizers to the cotton plant produced in the black land prairie section of Texas. Jour. Amer. Soc. Agron., 30:254–262. 1938.
6. RIGLER, N. E., ERGLE, D. R., and ADAMS, J. E. Some nitrogenous and other electrodialyzable constituents of the cotton plant at different stages of growth under differential fertilizer treatment. Soil Sci. Soc. Amer. Proc., 2:367–374. 1937.

THE "ALKALI TEST" AS A QUALITY INDICATOR OF MILLED RICE[1]

JENKIN W. JONES[2]

RICE varieties differ materially in milling and cooking quality. Millers naturally prefer varieties that give high yields of head rice (whole kernels) because unbroken kernels are the most valuable product obtained in rice milling. Consumers, on the other hand, are interested primarily in cooking quality. The kernels of different rice varieties may retain their shape after boiling and be either tender and flaky or firm and somewhat sticky, or they may break down into an unattractive pasty mass.

The observed differences in cooking quality are due apparently to variations in the size and shape of the kernels and to inherent differences in the character of starch in the kernels.

In breeding for improved quality a simple test is needed so that varieties and selections of undesirable cooking quality can be eliminated before carrying them through extensive tests. In general, differences in the chemical composition of varieties have not been found to be closely associated with their accepted culinary quality.

Warth and Darabsett,[3] however, reported that rice kernels of different varieties disintegrated in alkali solutions in a consistent order. Kernel disintegration and gelatinization was completed in some varieties in 24 hours, but in others it was incomplete after that time as indicated by a diffused white area adjacent to the kernels.

These studies suggested the possibility of using the alkali test as an indicator of culinary quality in rice varieties.

The experimental objectives reported here were to determine (1) the effect of a dilute solution of KOH on milled kernels of the rice varieties grown in the United States, (2) whether the effect of the solution on the kernels of a variety was consistent from year to year, and (3) whether the nature of kernel disintegration in the solution was associated with the cooking quality.

RESULTS

Milled kernels of seven varieties were tested in a 3% solution of potassium hydroxide in 1933. The kernels of Rexoro, Fortuna, Caloro, and Blue Rose disintegrated into clear masses in 24 hours and those of Early Prolific, Lady Wright, and Edith into opaque masses with white diffused areas near the kernels. The kernels of none of these varieties disintegrated in 24 hours in 1% or 2% solutions, but all disintegrated in a 2.38% solution. This strength was used in all subsequent tests because it indicated differences in varieties that were not so apparent in either weaker or stronger solutions. A stock solution of alkali was

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[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication August 26, 1938.

[2]Senior agronomist.

[3]WARTH, F. J., and DARABSETT, D. B. Disintegration of rice grains by means of alkali. Agr. Res. Inst., Pusa, Bul. 38. 1914.

made up each year by adding 100 grams of pure KOH to 2,000 cc of water. The solution was diluted to the desired strength when used. All tests were made at room temperatures of about 75° to 85° F, unless otherwise stated.

Mature panicles of varieties were collected at the four rice experiment stations in Louisiana, Texas, Arkansas, and California each fall from 1933 to 1936. After drying, seed from one panicle of each variety was milled for a uniform time in a "Minghetti rice mill," a small laboratory mill of the pearling cone type. Five milled kernels of each variety were then placed in a 2.38% solution of potassium hydroxide in Petri dishes. Four varieties usually were tested in one Petri dish. The appearance of the kernels was noted after 24 hours.

The appearance of the kernels of various varieties at the end of 24 hours is shown in Table 1. On the basis of disintegration, the samples were placed in three classes, *viz.*, clear, opaque, and intermediate. The varieties listed in Table 1 are placed in four groups on the basis of their reaction in the alkali solution. In all years tested, kernels of Blue Rose, Supreme Blue Rose, Zenith, Acadia, Caloro, and Colusa (group 1) disintegrated into clear masses and those of Early Prolific, Early Blue Rose (Wright's), Edith, and Lady Wright (group 2) from the southern states into opaque masses. The kernels of Early Prolific and Lady Wright from California also disintegrated into opaque masses in three of the four years tested.

Kernels of Fortuna, Rexoro, Iola, and Delitus, group 3, were clear in some years and intermediate in others. Kernels of Shoemed and Nira also were clear or intermediate, except for the 1936 samples from Texas. Intermediate samples of these varieties usually became clear in slightly stronger solutions. This, however, did not occur in varieties that were consistently opaque.

The kernels of Honduras, Vintula, Carolina Gold, Stormproof, and Mortgage Lifter, group 4, were not consistent in behavior from year to year. In most tests they were intermediate, but in others they were clear or opaque.

Variations in seasonal environmental conditions probably had more effect on the character of the starch in some varieties than in others. In this connection, it is of interest to note that the kernels of Honduras, Vintula, and Carolina Gold from California were clear, whereas kernels of the same varieties from Arkansas, Louisiana, and Texas were intermediate or opaque. Climatic conditions in California are very different from those in Arkansas, Louisiana, and Texas, and the effect of these differences on maturing of the rice kernels may account in part for the differences observed.

There is also the possibility that in some tests a panicle not representative of the variety was used, although precautions were taken to avoid such errors.

The effect of a 2.24% solution of alkali on the kernels of 16 varieties of rice is illustrated in Figs. 1 to 4.

The kernels of the Blue Rose, Supreme Blue Rose, Calady, Caloro, and Colusa varieties, group 1, all disintegrated into clear masses. Kernels of Early Prolific and Lady Wright, group 2, were opaque each in 15 of 16 tests. The two exceptions were kernels from the 1933

TABLE 1.—*Disintegration of kernels of rice varieties in a 2.38% solution of KOH.*

Variety	C. I. No.	Degree of disintegration after 24 hours*																Number of tests in which kernels disintegrated into masses that were			Total number of tests
		Louisiana crop of					Texas crop of				Arkansas crop of			California crop of							
		1932	1933	1934	1935	1936	1933	1934	1935	1936	1933	1935	1936	1933	1934	1935	1936	Clear	Intermediate	Opaque	
Group 1 (All Clear)																					
Blue Rose	1962	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	15	0	0	15
Supreme Blue Rose	5793	—	Cl.	—	Cl.	—	—	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	—	—	—	—	8	0	0	8
Calady	7786	—	Cl.	—	Cl.	Cl.	—	Cl.	Cl.	Cl.	—	Cl.	Cl.	—	Cl.	Cl.	Cl.	11	0	0	11
Zenith	7787	—	—	—	Cl.	Cl.	—	—	Cl.	Cl.	—	Cl.	Cl.	—	—	—	Cl.	7	0	0	7
241B(pl)31–2	—	—	—	—	—	Cl.	—	—	Cl.	Cl.	—	Cl.	Cl.	—	Cl.	Cl.	Cl.	8	0	0	8
Caloro	1561–1	Cl.	Cl.	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	Cl.	Cl.	Cl.	14	0	0	14
Colusa	1600	—	Cl.	Cl.	Cl.	Cl.	—	Cl.	Cl.	Cl.	—	Cl.	Cl.	—	Cl.	Cl.	Cl.	12	0	0	12
Acadia	1988	—	Cl.	—	—	—	—	Cl.	—	—	—	—	—	Cl.	Cl.	—	—	4	0	0	4
Group 2 (Mostly Opaque)																					
Early Prolific	5883	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Int.	Op.	Op.	Op.	0	1	15	16
Early Blue Rose (Wright's)	7790	—	—	—	Op.	Op.	—	—	Op.	Op.	—	—	Op.	—	—	—	—	0	0	5	5
Lady Wright	5451	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Int.	Op.	Op.	Op.	0	1	15	16
Latex	7788	—	Op.	—	Op.	Op.	—	Op.	Op.	Op.	—	Op.	Op.	Op.	—	Op.	Op.	0	0	11	11
Early Wright	—	—	Int.	Op.	—	—	—	Op.	—	—	—	Op.	Op.	—	—	—	—	0	1	4	5
Edith	2127	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Op.	Int.	Op.	Cl.	Int.	1	2	13	16
Group 3 (Mostly Clear and/or Intermediate)																					
Delitus	1206	—	Int.	Cl.	Int.	Int.	—	Cl.	Int.	Int.	—	Cl.	—	—	Cl.	Cl.	Cl.	6	5	0	11
Fortuna	1344	Cl.	Int.	Cl.	Int.	Int.	—	Cl.	Int.	Int.	—	Cl.	Int.	—	—	—	Cl.	5	6	0	11
Rexoro	1779	Cl.	Int.	—	Int.	Int.	—	Cl.	Int.	—	—	—	—	—	—	—	—	2	4	0	6
Nira	2702	—	—	Cl.	Int.	Int.	—	Cl.	Int.	Op.	—	Cl.	Cl.	—	—	—	Cl.	5	3	1	9
Iola	4559	—	Int.	—	Int.	Int.	—	—	—	Cl.	—	—	—	—	—	—	—	1	3	0	4
Shoemed	3625	—	Int.	Cl.	Int.	Int.	—	Cl.	Int.	Op.	—	Cl.	Int.	—	—	—	Cl.	4	5	1	10
Group 4 (Usually Intermediate)																					
Honduras	1643	—	Int.	Int.	Int.	Int.	—	Op.	Int.	Int.	—	Int.	Op.	—	Cl.	Cl.	Cl.	3	7	2	12
Vintula	1241	—	Int.	Int.	Int.	Int.	—	Int.	Op.	Int.	—	Cl.	Op.	Cl.	—	Cl.	—	3	6	2	11
Carolina Gold	1645	—	Int.	—	Int.	Op.	—	Int.	Int.	Int.	—	Cl.	Int.	—	Cl.	—	Cl.	3	6	1	10
Stormproof	7705	—	Int.	Int.	Int.	Op.	—	Op.	Int.	Int.	—	Op.	Int.	—	—	—	—	0	6	3	9
Mortgage Lifter	5550	—	—	—	Int.	Int.	—	Op.	Op.	Int.	—	Int.	Op.	—	—	—	—	0	4	3	7

*Cl. = Clear; Op. = Opaque; and Int. = Intermediate.

California crop that were intermediate. These results indicate that the character of the starch in these two groups of varieties probably is inherently different, accounting for the fact that in each group the nature of the disintegration of the kernels in alkali solutions was consistent, except as noted.

FIG. 1.—Kernels just after placement in the solution at 10:45 a.m., June 17, 1938. 1, Blue Rose; 2, Early Prolific; 3, Calady; 4, Early Blue Rose; 5, Caloro; 6, Lady Wright; 7, Colusa; 8, Edith; 9, Fortuna; 10, Honduras; 11, Rexoro; 12, Vintula; 13, Nira; 14, Carolina Gold; 15, Delitus; and 16, Stormproof.

The kernels of Fortuna, Rexoro, Nira, and Delitus, group 3, were about equally divided between clear and intermediate types of disintegration. This indicates that in these varieties the character of the starch deposited in the kernels is probably more easily affected by environmental conditions than that of the varieties listed in either groups 1 or 2. The kernels of Honduras, Carolina Gold, Stormproof, and Vintula, group 4, were also inconsistent in type of disintegration. It is also possible that the starch of the varieties listed in groups 3

and 4 may consist of a mixture similar in some respects to that present in varieties of groups 1 and 2. Warth and Darabsett[4] have shown that a portion of the starch in some rice varieties is liquefied at relatively low temperatures, while the remainder requires a higher temperature for liquefication.

FIG. 2.—Kernels of 1, Blue Rose; 3, Calady; 5, Caloro; and 7, Colusa began to disintegrate 1¾ hours after being placed in the solution (12:30 p.m., June 17, 1938).

The kernels of Blue Rose and Caloro, group 1, which were consistently clear, are usually rather firm and slightly sticky when cooked by boiling. Kernels of Fortuna and Rexoro, group 3, are usually tender and flaky after cooking. Early Prolific and Lady Wright, group 2, from the South, which were consistently opaque, do not hold their shape so well in cooking and are likely to be pasty and of inferior quality.

Fortuna and Rexoro of group 3 are believed to be superior in culinary quality to Blue Rose and Caloro of group 1, and Blue Rose is

[4]WARTH, F. J., and DARABSETT, D. B. The fractional liquefication of rice starch. India Dept. Agr. Mem. Chem. Ser., 3(5):135–146. 1914.

likewise believed to be superior to Early Prolific of group 2. In general, therefore, there appears to be some association in certain varieties between the type of kernel disintegration in an alkali solution and the cooking quality. The kernels of varieties believed to be of the best (tender and flaky) culinary quality usually were clear or intermediate

FIG. 3.—Kernels of all varieties began to disintegrate 5¾ hours after placement in the solution (4:30 p.m., June 17, 1938). There was more disintegration in 1, Blue Rose; 3, Calady; 5, Caloro; and 7, Colusa kernels than in those of the other varieties. The varieties most resistant to disintegration were 2, Early Prolific; 4, Early Blue Rose; 6, Lady Wright; and 8, Edith.

(group 3), and those believed to be of poorer quality were opaque, group 2. The varieties listed in group 4, which were the least consistent in behavior, are also believed to be of better cooking quality than most of those listed under groups 1 and 2.

Early Prolific and Blue Rose are medium-grain varieties and the cooking quality of Early Prolific, of opaque reaction, is generally believed to be less desirable than that of Blue Rose, of clear reaction. Likewise, the cooking quality of the long-grain variety, Lady Wright,

of opaque reaction, is believed to be less desirable than that of the long-grain varieties Fortuna, Rexoro, and Nira, which were of clear or intermediate reaction. Edith and Lady Wright, long-grain varieties, were both opaque in reaction but Edith is believed to be of better

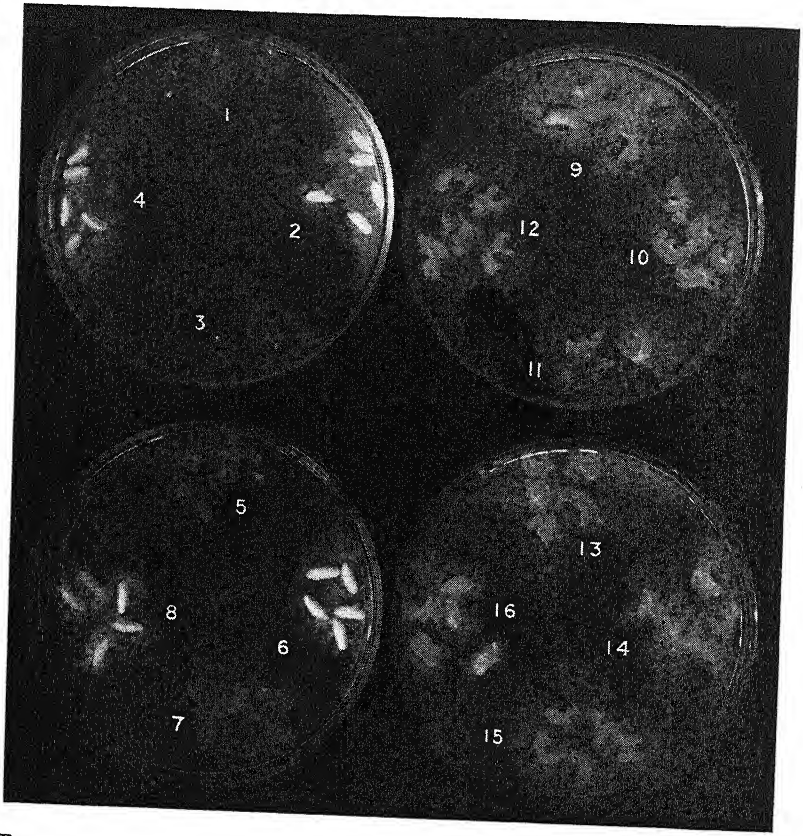

FIG. 4.—Twenty-four hours after placement in the solution (10:45 a.m., June 18, 1938) the kernels of 1, Blue Rose; 3, Calady; 5, Caloro; and 7, Colusa disintegrated into clear masses; those of 2, Early Prolific; 4, Early Blue Rose; 6, Lady Wright; and 8, Edith were more resistant and opaque; and those of 9, Fortuna; 10, Honduras; 11, Rexoro; 12, Vintula; 13, Nira; 14, Carolina Gold; 15, Delitus; and 16, Stormproof disintegrated more completely and were somewhat less opaque than 2, Early Prolific; 4, Early Blue Rose; 6, Lady Wright; and 8, Edith.

cooking quality than Lady Wright. Varieties showing the same reaction may differ in cooking quality but probably to a lesser extent than varieties of different reaction.

The results, while not so consistent as might be desired, do indicate that a simple test of this nature may be used to advantage in preliminary testing for quality.

Rice varieties that differ materially in kernel size or shape, in the time required for cooking, or in their reaction to alkali solutions should not be blended or mixed when placed on the market.

EFFECT OF TEMPERATURE

Tests in an alkali solution were made in 1935 at constant temperatures of 20°, 25°, 30°, and 35° C. The kernels of Blue Rose, Caloro, Rexoro, and Iola appeared to be more completely disintegrated at 30° and 35° than at 20° and 25° C, whereas those of Early Prolific and Lady Wright were more completely disintegrated at 20° and 25° than at 30° and 35° C. Kernels of Early Prolific and Lady Wright, as has been stated, are more resistant to disintegration in alkali solution than are those of Blue Rose, Zenith, Caloro, and other varieties that usually disintegrated into clear or intermediate masses.

TESTS OF SAMPLES FROM COMMERCIAL MILLS

In the fall of 1937, 29 samples of milled Early Prolific and 46 samples of milled Blue Rose rice were obtained from commercial mills in Arkansas, Louisiana, and Texas. All kernels from 26 of the Early Prolific samples tested in an alkali solution were opaque. In the other three samples from 2 to 8% of the kernels were clear, similar in appearance to those of disintegrated Blue Rose.

The kernels in 19 of the Blue Rose samples were all clear, but in the remaining 27 samples from 4 to 36% of the kernels tested were opaque, similar in appearance to those of Early Prolific.

Of the 46 Blue Rose samples tested, 58.7% thus contained mixtures of opaque kernels similar in appearance to disintegrated Early Prolific, whereas only 10.3% of the 29 Early Prolific samples contained mixtures of clear kernels that reacted like those of Blue Rose. These results indicate that milled rice consisting of a mixture or blend of kernels of the same shape and appearance but that are clear and opaque in reaction can be detected with reasonable certainty.

SUMMARY

A simple test for quality is needed in breeding rice to permit the discarding of varieties and selections of inferior quality after preliminary nursery tests. Data on an "alkali test" as an indicator of culinary quality are presented here.

Milled kernels of rice varieties were immersed in a dilute solution of potassium hydroxide and the nature of kernel disintegration was observed.

The type of disintegration was consistent in all samples of certain rice varieties but was inconsistent in others.

There is evidence of some association in cooking quality and the type of kernel disintegration. Varieties of similar grain types in which the kernels disintegrate into clear and/or intermediate masses in general are believed to be of better cooking quality than those that disintegrate consistently into opaque masses.

The alkali test permits the detection of certain common though undesirable varietal mixtures of milled rice.

NOTE

A NEW CLOVER FOR THE BLACK LANDS IN THE SOUTH

A CLOVER that is locally called "Wild European clover," or Lappacea clover (*Trifolium lappaceum*), has shown that it may become very valuable on the heavy clay soils of the "Black Belt" of Alabama and other southern states. This clover, so far as is known, was first found in this country in 1923. It was first found along the railroad at Snow Hill, Alabama, and was reported by Doctor A. J. Pieters in SCIENCE, Vol. 59, No. 1515, pages 39 to 40, in 1924. It was sent in to the U. S. Dept. of Agriculture for identification from Mississippi in 1926. In 1929 one plant was found in a field of oats near Marion Junction, Alabama. At present this farmer has 230 acres of land with this clover on it.

In 1935 it was found on a farm near Montgomery, Alabama. At present this farmer has about 40 acres in the clover. In 1938 many other scattered patches of the clover have been reported over various parts of the Black Belt.

The plant is a creeping annual with a dense pubescence on the leaves and stems. On good soil it reaches a height of 18 inches. It produces a large yield of hay and is an excellent pasture plant. It produces an abundance of seed which are a little larger than those of white clover. It reseeds when pastured or when cut for hay. The seed germinate in the fall and the plant reaches a height of 4 or 5 inches in February. It makes rapid growth in the spring and dies in June. It is not known how far north it is cold-hardy, but it has never been killed by cold in middle Alabama. A few seed are available for distribution by the Agronomy Department of the Alabama Experiment Station to experiment station workers who may be interested in testing it in an introductory way.—D. G. STURKIE, *Alabama Agricultural Experiment Station, Auburn, Ala.*

BOOK REVIEWS

FARM GAS ENGINES AND TRACTORS

By Fred R. Jones. New York: McGraw-Hill Book Company, Inc. Ed. 2. XII+486 pages, illus. 1938. $3.75.

THIS is the second edition of the book by the same name, published in 1932. An important change is the rearrangement of material so that the two parts of the preceding edition are combined, thus eliminating the duplication that necessarily followed the division into a part which treated of the fundamentals of simple internal-combustion engines and the small stationary farm-type engine, and a part which then considered the detailed construction and operation of farm tractors.

New chapters are added on Diesel engine construction and operation, fuels and their character, and electric starting and lighting equipment. Illustrations are brought up-to-date in conformity with the rapid changes that have taken place in recent years.

It is primarily adapted as an up-to-date textbook for use in agricultural colleges, but should also prove useful to mechanics, service men, and owners and operators. (H. B. T.)

THE PRINCIPLES OF SOIL SCIENCE

By Alexius A. J. de Sigmond. Translated from the Hungarian by Arthur B. Yolland. Foreword by Sir John Russell. London: Thomas Murby & Co. XIV+362 pages, illus. 1938. 22/6 net.

THIS book is a translation and adaptation for English students of one of somewhat longer form published in Hungarian some years ago by Prof. de Sigmond. It aims primarily at presenting, fairly exhaustively, the present status of the science of pedology and deals with genetics, agronomy, systematics, and cartography. The author, who himself felt the importance of an English translation, undertook the work and made the adaptation to the English student. This latter consisted in omitting details of more local interest and also the sections in the original which dealt with soil physics and soil microbiology in which, as Prof. de Sigmond states, "English soil literature is already so rich".

It seems superfluous to say much concerning the volume's contents since the author himself states that it is an almost full outline of the subjects covered and deals with both the author's work and that of other soil scientists.

As Sir John Russell intimates in his foreword, any book on soil science by such an internationally recognized authority as Prof. de Sigmond is sure to be of great value to other soil scientists of the world.

Besides some 38 illustrations the volume also has a good subject and author index. (R. C. C.)

THE SOILS OF PALESTINE: STUDIES IN SOIL FORMATION AND LAND UTILIZATION IN THE MEDITERRANEAN

By A. Reifenberg. Translated by C. L. Whittles. London: Thomas Murby & Co. VIII+131 pages, illus. 1938. 14s. net.

THE author of this little book is a lecturer on agricultural chemistry and soils in the Hebrew University in Jerusalem, while the translator is soil chemist at the West of Scotland Agricultural College.

The purpose of the volume seems to be to bring before the minds of those interested the present status of the soils of Palestine from the standpoint of fertility and erosion losses.

The author is especially interested in the problems presented by Mediterranean type soils which he says have been steadily deteriorating for fifteen hundred years. The subject is especially pertinent at present in light of the new Jewish immigration. In fact the last chapter of the book is given over to the history and present status of the Zionist colonisation movement.

For the most part the book is a technical treatment of the problems involved and includes considerable data and discussions of the processes of formation of Palestine soils, the effect of Mediterranean

climate on soil formation, crop adaptation, irrigation, and manuring problems. There are 10 illustrations and a number of figures in the text, also a bibliography at chapter ends. The contents should be valuable to those interested in the climatic aspects of soil formation. (R. C. C.)

SOILS OF THE LUSITANO-IBERIAN PENINSULA

By Emile H. del Villar. Translated by G. W. Robinson. London: Thomas Murby & Co. 416 pages. 1937. Paper cover; also, map in separate folder. 40/ net.

THE author of this work is a Spanish geobotanist and edaphologist, also president of the Mediterranean Subcommission of the International Society of Soil Science. Prof. Robinson in his translation has somewhat abridged the original. The volume is rather large owing to the fact that the translator presents each chapter first in Spanish then in English. The volume takes up classification and nomenclature, acid-humic soils, siallitic soils, calcareous soils, saline soils, alluvial soils and modification of these. At the end of each chapter are given many analyses of the soils described.

The text contains a few plates, is printed on good paper with clear type, but has no index or table of contents. The accompanying map is a large folding one with a description given at the end of the main volume. It can be furnished by the publishers, rolled and suitable for hanging.

As the translator states, the study of pedology is world wide and a worker who is acquainted only with the soils of his own country has only a partial view of the subject as a whole. (R. C. C.)

CHROMOSOME NUMBER RELATIONSHIPS IN THE LEGUMINOSAE

By Harold A. Senn. Bibliographia Genetica XII: 175-336. 1938.

THIS is a cytological monograph of the family comprising the chromosome numbers in 436 species of 74 genera. The frequency of polyploidy in the Leguminosae is very low, only 23% being polyploids or dervied from polyploids. Intraspecific polyploidy is rare and intrageneric polyploidy of only occasional occurrence. Intergeneric and intergroup aneuploidy is a common relationship, but intrageneric and intraspecific aneuploidy is less common. Northern and wide distribution is not always associated with polyploidy. Higher chromosome numbers are associated with perennial condition. The woody legumes were found to have on the average higher chromosome numbers than the herbaceous ones. A number of instances among closely related races or species are cited where the perennial has the higher number. These findings indicate that in the Leguminosae at least some of the woody perennial species may have arisen from herbaceous annual ancestors.

A phylogenetic tree is given from which the following lineages may be mentioned: From the base line of primitive Papilonatae springs a branch carrying the Sophoreae with 9 and 14 chromosomes and the closely related Podalyrieae (9) and the related Caesalpinioideae.

From the same root but on a different branch are the Galegeae (8, 7, 6, 10, 11) with the Loteae (8, 7, 6) and the Hedysareae (8, 7, 9, 10, 11, 20) more distally attached.

Three other main stems spring from the base line all assumed to have the basic number 8. These main stems are interrelated in the following way: The Grotalarinae (8) and Spartiinae with the Cytisinae (12, 24) stem from the Genisteae which through Ononis (15, 16) connect with the second main stem carrying the Trifolieae (8, 7). The closely related Cicer (7, 8) and Vicieae (7, 6, 5) connect the first and second main stem with the third carrying Abrus (11)and the closely related Phaseoleae (11, 12, 8, 20, 21).

The literature list covers 12 pages. There are 102 figures among which 15 maps, 2 frequency distribution graphs on annual and perennial, herbaceous and woody members related to chromosome number, 2 polygons on diploidy and polyploidy, and all original counts are authenticated by original drawings. (B. R. N.)

AGRONOMIC AFFAIRS

SUMMARY AND INDEX OF WPA RESEARCH PROJECTS

THE results of some 2,000 research projects carried on as part of the Federal work relief program are summarized briefly in a digest and index which has been published by the Works Progress Administration. This volume of 291 pages contains a concise statement of the principal conclusions of each study and an alphabetical subject index to the contents. The reports on these projects touch upon nearly every field of natural and social science and many of them have appeared in the form of articles in scholarly journals. However, several hundred of the reports summarized in this index are in manuscript form, and arrangements have been made with the American Documentation Institute whereby micro-film copies of the original reports will be furnished at nominal rates for the use of research specialists.

A small edition of this volume has been prepared for distribution to the larger public and university libraries, where it will be available for reference, and for government departments, industrial concerns, and research foundations. A limited supply of copies of this Index of Research Projects are still available. Requests should be addressed to the Works Progress Administration in Washington.

BIBLIOGRAPHY ON MINOR ELEMENTS AND PLANT NUTRITION

A THIRD edition of "Bibliography of References to the Literature on the Minor Elements and Their Relation to the Science of Plant Nutrition" is contemplated by the Chilean Nitrate Educational Bureau early in 1939. It is expected that the volume will include approximately 4,700 abstracts and references.

In order to meet requests for this edition, the Bureau is desirous of knowing as far in advance of publication as possible what the demand will be. Copies may be obtained at the nominal charge of $1.00 to cover printing and postage. Orders should be placed with the Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York City.

FILM-STRIP PRICES

PRICES for film strips issued by the U. S. Dept. of Agriculture for the fiscal year 1938–39 are lower than those that were in effect during the past fiscal year, according to an announcement recently made by the Extension Service of the Department. Photo Lab, Inc., 3825 Georgia Avenue, N. W., Washington, D. C., was awarded the contract for film-strip production as the result of the low bid they submitted in competition with other firms.

The prices for film strips until June 30, 1939, will range from 45 to 65 cents each, depending upon the number of illustrations in the series. The majority of the 300 series that the Department has available will sell for 45 or 50 cents each. Film strips are available on such subjects as soil conservation, farm crops, dairying, farm animals, farm forestry, plant and animal diseases and pests, roads, farm economics, farm engineering, home economics, and adult and junior extension work. Lecture notes are provided with each film strip purchased, with the exception of those that are self-explanatory.

A list of available film strips and instructions on how to purchase them may be obtained by writing to the Extension Service, U. S. Dept. of Agriculture, Washington, D. C.

ABSTRACTS OF ROUND-TABLE CONFERENCE

MIMEOGRAPHED abstracts of the round-table conference on "Comparative Nutritive Value of Crops to Bring Out the Comparison and Advantages of Pasture and Hay Compared with Other Crops in Cost of Digestible Nutrients" have been prepared by Professor O. McConkey, Ontario Agricultural College, Guelph, Ontario, Chairman of the conference. The conference was held under the auspices of the joint Canadian and American Committee on Pasture Improvement at Ottawa in June, 1938, at the time of the summer meeting of the A. A. A. S.

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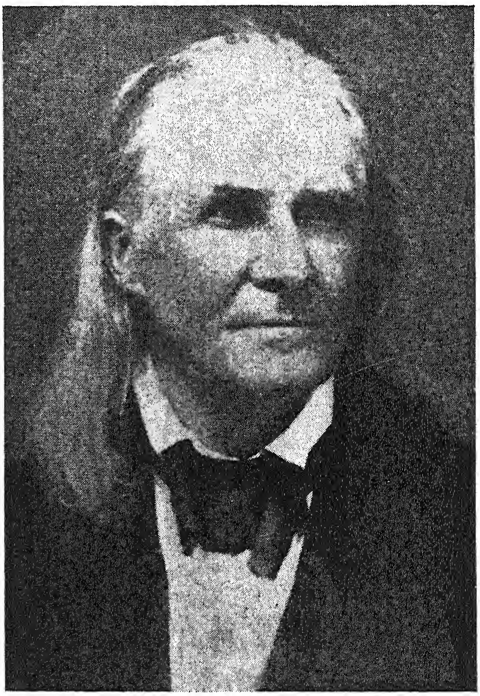
PUTTING SOIL SCIENCE TO WORK[1]

EMIL TRUOG[2]

JUST 120 years ago, soil science in America was put to work for the first time. The honor of doing this goes to Edmund Ruffin, whose father having died in 1810, was in 1813, at the age of 19, left in charge of a large plantation at Coggin's Point, located in the tide water area of Virginia. Not only because Edmund Ruffin was the first man in America to put soil science to work, but also because of the peculiar circumstances under which this was done, the speaker deems it appropriate to devote a large portion of this address to Ruffin's work.



EDMUND RUFFIN (1794–1865)

A successful farmer, father of soil chemistry in America, first to contend that upland mineral soils in the humid region are often acid, foremost authority of his time on the liming of land, brilliant writer, public benefactor, and a great patriot.

Edmund Ruffin, born in 1794, was in youth frail of health and restless of spirit. He read much of whatever came to hand and grew up in almost complete ignorance of the practical

[1]Presidential address delivered before the thirty-first annual meeting of the Society held in Washington, D. C., November 17, 1938.

[2]Professor of Soils, College of Agriculture, University of Wisconsin, Madison, Wis.

agricultural tasks which now faced him. After some elementary schooling, probably by his parents or private tutors, he left home for the first time at the age of 16 for Williamsburg to enter William and Mary College. His career there was short, having met Susan Travis, he soon returned home to take her in marriage, and then to enlist as a private in the War of 1812. After six months of military routine, he was mustered out, after which he immediately assumed control and direction of the Coggin's Point farm.

In attempting to give you a picture of the state of agriculture in Virginia at the time Ruffin started farming, and of the problems that Ruffin faced, I can do no better than to quote at length from Avery Craven's charming book entitled, *Edmund Ruffin, Southerner*[3] (pages 49 to 54). The quotation follows:

"'Of grain and pulse they provide commonly no more than they reckon that their families will require, for there are no towns as markets where they can sell them. . . . The one thing of which they make as much as they can is tobacco, there being always a vent for that at one time or another of the year.'

"Thus wrote an Old World observer of Virginia agricultural practices at the end of the seventeenth century. Unwittingly he had placed his finger on the central fact in the colonial history of the Old Dominion. Beginning in a wilderness, the early settlers had faced the possibility of a rapid degeneration to a grinding simplicity wherein every man and every group fashioned, from the materials the immediate environment afforded, the sum total of their consumption. Only the fortunate development of a profitable surplus of tobacco prevented a rapid lowering of standards and enabled them to procure, by exchange with the Old World, the comforts and luxuries of a mature and complex life and to reproduce in the forest a bit of 'merry England' itself, 'transported across the Atlantic. . . more merry, light and joyous than England had ever thought of being.'

"But it led, also, to the elevation of the first of those despotic Southern kings who brought so much of misery to their subjects. To base upon one staple alone, the whole of a standard of living centuries too old for its environment meant the establishment of a single-crop type of agriculture in which the sole object was immediate great yields regardless of future consequences. Such a system, under frontier scarcity of capital and labor, threw the burdens of abnormal production squarely upon the land, in a region where sod formation was poor, rainfall heavy and concentrated, and the harmful microorganisms unusually active. There could be but one result. Tobacco-growing meant soil exploitation, unit expansion, and ultimate abandonment of once fertile fields.

"Just what was implied is revealed in the comment of a second observer, three-quarters of a century later. 'The Virginians of the lower country are very easy and negligent husbandmen,' he wrote. 'New land is taken up, the best to be had, tobacco is grown on it for three or four years and then Indian corn as long as any will come. And in the end, if the soil is thoroughly impoverished, they begin again with a new piece and go through the rotation.' He pictured a world of widening fields and retreating forests; white servants, come to toil, giving way to negro slaves under pressure for economy; acres growing weary, falling from cultivation, and returning again to forest; in time, planters frayed a bit at the cuffs, out at the elbows, down at the heels, bitter and complaining, as farmers are wont to be, of returns that did not pay the cost of production. And then, while some held on,

[3]New York: D. Appleton and Company. 1932.

shifting crops and yielding standards, others, more easily discouraged or more quick to accept the inevitable, according to the point of view, turned west, leaving the bones of their ancestors to keep watch in old familiar neighborhoods while they began over again where lands were fresh and cheap and debts were no disgrace.

"Such a system, of necessity, ran its course in the older regions well before the American Revolution. Many planters turned farmer, dividing their lands and labor forces into smaller units, shifting production to wheat and corn, and seeking markets that lay outside the grip of the British merchant and his much despised Scotch agents. But the Revolution interrupted adjustments, adding its ruin to an already bad situation, which did not greatly improve for the masses until the French Revolution and its spread gave to the American farmers the profitable task of furnishing food to those whose efforts were absorbed by war. A few great planters, such as Washington, Jefferson, and Madison, led the way to changes for the better conservation of the soil, while such specialists as John Binns and John Taylor of Caroline preached a new gospel of fertilizers and crop rotation which would have altered fundamentally the whole agricultural procedure. But uncertain profits checked wide change, and the Peace of Ghent threw the whole old tobacco world back in ruins, sighing 'for another Napoleon to restore to us by his wars the feeding of Europe.'

"Thus, when Edmund Ruffin, just turned nineteen, took over the responsibilities of a planter on weary lands, the situation represented the accumulations of two centuries of bad methods. Plows and plowing were poor. Iron moldboards were just coming into use, but the great majority, suspicious of anything new, preferred to go on with their old implements, cutting shallow furrows up and down the hillsides to become veritable watercourses of destruction in time of rains. Furthermore, the rotation of crops, though followed by a few, met serious difficulties in the failure of clover or other legumes to grow on poor lands, which cut the supply of livestock and manure and precluded the profits that would have made possible the purchase of artificial fertilizers. Slaves multiplied out of proportion to agricultural needs, becoming a burden on masters and fields until the strong paternal sense which characterized the institution in this region weakened to permit the sale of the human surplus into the spreading cotton fields of the 'Lower South.' Tattered and briary, the lands lapsed back to become the haunts of deer and wild turkey, while stolid men and patient women plodded on with a persistence too mechanical to have been born of courage. Agriculture was steadily yielding ground in both a real and a figurative sense.

"Travelers and natives alike in this period (1815–1830) agree on the impression that an 'angel of desolation had cursed the land,' many tracts presenting scenes of ruin 'that baffle description—farm after farm . . . worn out, washed and gullied, so that scarcely an acre could be found in a place fit for cultivation;' 'dreary and uncultivated wastes, a barren and exhausted soil, half clothed negroes, lean and hungry stock, a puny race of horses, a scarcity of provender, houses falling to decay, and fences wind shaken and dilapidated.'

"Meanwhile 'an emigrating contagion resembling an epidemic disease' had seized the people. 'Thousands . . . in the hopelessness of bettering their condition in their native land' abandoned 'the beloved homes of their nativity.' The rate of population growth in Virginia fell from thirty-seven and a half per cent in 1820 to thirteen and a half per cent in 1830 and then to only a trifle over two per cent in the next decade. Many counties lost population, and there were over 388,000 Virginians in other states in 1850. Ruffin himself later declared: 'There was scarcely

a proprietor in my neighborhood . . . who did not desire to sell his land, and who was prevented only by the impossibility of finding a purchaser, unless at half of the then very low estimated value. All wished to sell, none to buy.' And what was true of lower Virginia applied with equal force to the older portions of Maryland and the Carolinas. The prospects for a young planter were, indeed, gloomy.

"With an enthusiasm born of youth and theories developed from childhood reading, Ruffin assumed his task. His lands at Coggin's Point were extremely poor, 'the larger part not averaging more than ten bushels of corn per acre, no more than six bushels of wheat, on the better half.' From experiment to experiment he moved, failure dogging his steps. He drained his better swamp lands only to find their yields, after three years of good crops, so reduced as to necessitate abandonment. He turned to John Taylor's much discussed system of 'enclosing,' receiving 'as sound and true every opinion and precept,' but ended in 'utter disappointment.' The manure he applied 'produced little of the expected effect on the first course of crops and was scarcely to be perceived on the second.' Clover would not grow for him, and 'the plowing on hilly land . . . into ridges, caused the most destructive washing away of soil by heavy rains.' After four or five years of trial Taylor's methods 'proved either profitless, entirely useless or absolutely and in some cases greatly injurious.' He was forced to admit that no part of his 'poor land was more productive than when . . . (his) labors commenced and that on much of it, a tenfold increase had been made of the previously large space of galled and gullied hillsides and slopes.'

"Old residents, grown weary in the struggle, had long since concluded that lands in this part of the state could not hold manure or be enriched. They smiled in tolerance as the young theorist continued to reject this 'monstrous agricultural heresy' but did not withhold the 'I told you so' when at last he too 'was compelled, most reluctantly, to concur in this opinion.' He had failed. He would seek 'the rich western wilderness' where his 'whole income and more' would not be required for the most economical support of his 'small but fast growing family.' Not the lure of verdant fields in Kentucky or Alabama stirred him, but benumbing pressure weighing heavily on one who thought of the future in terms of children and even slaves who must have the things that a gentleman gives to his dependents."

In such a frame of mind Ruffin had the good fortune of having a copy of Davy's *Agricultural Chemistry*, first published in 1813, fall into his hands. It was probably more than mere chance that this happened, for Ruffin, in his intense zeal to find some solution to the baffling problems of soil management that faced him, was apparently combing all available sources of information. Although Ruffin states that his limited knowledge of chemistry was obtained without aid or instruction, his keen, analytical mind apparently made it possible for him to master the contents of Davy's book in short order. His attention was particularly attracted to a statement to the effect that a sterile soil containing "the salt of iron, or any acid matter. . . . may be ameliorated by the application of quicklime."

In Davy's book he found directions for testing soils for soluble iron, calcium, and calcareous earth and also testing limestone and marl for their carbonate content. Ruffin immediately assembled the necessary equipment and chemicals for making these tests. Although he was not able to reveal the presence of free acids in his soil, he did show that carbonates were absent, and having observed that sorrel and pine

abounded on poor soil, he was led to the independent conclusion that "vegetable acids" were the cause of sterility in his soils. Ruffin was thus probably the first man in the whole world to conclude that upland mineral soils are often acid due to the presence of free acids, made possible by the absence of calcareous earths. In defense of this conclusion, he presented arguments which were in advance of some presented by trained chemists nearly a century later. He observed for example, that drainage waters from non-calcareous soils are often darker in color than those from calcareous soils, due, he contended, to the solubility of the free organic acids and insolubility of the lime salts of these acids. He also held that all fertile soils are either calcareous or hold lime in combination with acids in such form that it is easily extracted with hydrochloric acid. The thoroughness of Ruffin's consideration of the subject is evidenced by his detailed reference to the work on humic acids which Berzelius was doing at about that time. He also refers to the work of Sprengel and others.

Although litmus paper was used by the chemist as early as 1807 to detect acidity and alkalinity in the laboratory[4], yet Davy makes no mention of its use in testing soils. The earliest references to the use of litmus paper for testing the reaction of soils that the writer has traced are one by Thaer[5] in 1856 and one by Voelcker[6] in 1865. One can well imagine the thrill Ruffin would have experienced had the litmus paper test been available to him so that he might have given positive demonstration of the general prevalence of acidity in upland mineral soils of the humid region. At any rate, his conclusion that upland mineral soils are often quite sterile due to an acid condition was essentially true. With the aid of the test for carbonates, Ruffin located deposits of marl on his farm and at other places in the neighborhood. He now decided to make an actual test of his theory. Quoting again from Avery, page 55:

"On a February morning in 1818 his carts began to haul the marl that puzzled negro hands dug from pits hastily opened on his lower lands. They spread some two hundred bushels over a few acres of newly-cleared, but poor, ridge land, and in the spring he planted the entire field to corn as a testing crop. Eagerly he waited. As the season advanced, he found reason for joy. From the very start the plants on marled ground showed marked superiority, and at harvest time they yielded an advantage of fully forty per cent. The carts went back to the pits. Fields took on fresh life. A new era in the agricultural history of the region had dawned.

"With all the ardor of a discoverer Ruffin immediately set about to widen his knowledge by extended experiments and to spread the information which offered so much to his fellow planters and to his section. In October of that year he presented to the agricultural society of his own county the first of what was to be a long list of valuable papers offered to the cause of agriculture. Stating his theories as 'to the nature of soils and the action of calcareous manures' on them, he adduced the slender sum of his experience to support what was, in fact, a revolutionary approach to the whole problem that vexed the farmers of the New World. While the great rural hosts, facing westward, moved steadily forward to the ex-

[4]Die Apotheker-Kunst, von Trommsdorff. 1807.
[5]Principles of Agriculture, page 184, New York. 1856.
[6]Jour. Roy. Agr. Soc., 1 (2 Ser.): 113–130. 1865.

ploitation of a continent's virgin fertility in the name of progress, he offered a new program of restoration which had as its purpose an 'about face' induced by the creation of opportunity in the lands of the older regions. He would save the Old South. He would commit that greatest of all agricultural crimes—he would rely on theory and books!"

In the language of my address tonight, he would put soil science to work. Quoting further from Avery, page 56:

"Three years later this paper, revised and enlarged, was published in the *American Farmer*, the new agricultural journal that John Skinner had started in Baltimore. The editor hailed it as 'the first systematic attempt . . . wherein a plain, practical, unpretending farmer has undertaken to examine into the real composition of the soils which he possesses and has to cultivate. So fundamental did he consider the contribution that an extra edition of this issue was printed to be distributed gratuitously to the farmers of the country. Eleven years later, grown into a volume of 242 pages, it appeared again under the title, AN ESSAY ON CALCAREOUS MANURES, to run through five editions and to be called at the end of the nineteenth century by a government expert, writing in the YEAR BOOK OF THE UNITED STATES DEPARTMENT OF AGRICULTURE, the most thorough piece of work on a special agricultural subject ever published in the English language. Contemporary writers, who have been lifting their jeremiads amid the agricultural ruins and 'the draining off of our most independent citizens to the West,' hailed him as a deliverer, taking rank at once with the great John Taylor of Caroline whose ARATOR had been the first cry in the wilderness. Even the doors of politics swung open to him, and in time a president of the United States would declare that his ESSAY 'in its valuable consequences' would 'be worth more to the country than all the state papers that have been the most celebrated in our time.' Over John Tyler's mantel Edmund Ruffin's portrait would hang as a companion piece to that of Daniel Webster—the greatest American agriculturist and the greatest American statesman!"

In the light of this rather extended review of Edmund Ruffin's work relative to scientific and practical soil management, I think you will all agree that Edmund Ruffin, as Craven says, "has good claim to be called the father of soil chemistry in America". Some of you have read George Washington's difficulties in the culture of alfalfa and, even, clover. Washington was thoroughly familiar with the agricultural writings of the foremost authorities in England of his time. He was, in fact, in regular communication with no lesser authority than Arthur Young. It was impossible, however, for Washington to obtain much aid, even from the foremost authorities, because soil chemistry was just being born at the time of his death in 1799. Davy's writings on agricultural chemistry had, as yet, not appeared.

Washington practiced erosion control to some extent, took special pains to conserve animal manure, went to great labor in fertilizing with mud obtained from creeks and marshes, and spent much money in the purchase of special seeds, nevertheless, he was unable to materially increase production or even maintain the level of soil fertility. Had he known that his soil was acid and needed lime (the U. S. Soil Survey map shows that the crop lands of Washington's Mount Vernon

Farms consist largely of Keyport silt loam which lacks lime even under virgin conditions), he undoubtedly would have applied the lime, and then clover and even alfalfa would have grown so that the nitrogen and organic matter supply of his land might have been maintained or increased. The use of lime would probably have deferred the advent of failing crops by 25 to 50 years, that is, until phosphorus and potassium became limiting elements. The agricultural situation in 1834, 35 years after Washington's death is expressed by Craven (page 63) as follows:

> "By 1834 a visitor to 'Mount Vernon,' where the great Washington had struggled for better methods, declared that 'a more wide-spread and perfect agricultural ruin could not be imagined.' Jefferson at 'Monticello' was closing his days in poverty as his fields and markets failed him; everywhere the agricultural societies dwindled for lack of support as farmers lost heart; and even John Binns and his gypsum yielded ground."

In order that he might give his discoveries relative to the use of lime greater publicity, and that better methods in agriculture might be promoted, Ruffin in 1833 launched his agricultural periodical called the *Farmers' Register*. This publication was called by John Skinner, a prominent editor, to be the "best publication on agriculture which this country or Europe has ever produced."

Ruffin also purchased another estate of nearly 1000 acres of choice land in Hanover County, Virginia, which he appropriately called "Marlbourne". He had no sooner moved to this new estate in 1843, when he set to marling 800 acres or more in preparation for clover. He installed a system of drainage, gave most careful attention to the preservation and use of barnyard manure, and persisted with his trials until clover grew too rank for his machines to cut. The results of scientific farming were soon manifest, for in the period 1845 to 1848, his yields per acre of wheat increased from 15 to 20 bushels, and corn from 14 to 29 bushels. His profits on wheat alone for one year were nearly $6,000.

I would not have you believe that Ruffin was the first man in America to use lime for we have definite reference that liming of land was practiced to some extent in Colonial days, particularly in Pennsylvania and New Jersey. As is well known, history records definitely that liming of land was practiced long before the Christian Era. Undoubtedly here and there long before the dawn of history, man scattered ashes from his fire or marl from the pit, over land which he later planted to crops and noted marked improvement in his harvest therefrom. At another time and place he repeated the practice but the results were not favorable. He knew not why for his results were empirical and there was no soil science which might be put to work. Thus he dropped the practice as did others that followed him. By the time of the Romans, however, there had accumulated a sufficient body of favorable results from the liming of land that their writers on agriculture were disposed to give the matter considerable prominence. In Britain, the liming of land may have antidated the invasion by the Romans, since lime in the form of chalk and marl is there so plentiful. Hall states "The regular use of some form of lime or chalk

was part of the accepted routine of farming as early as we possess any records of British agriculture, and among the manures it figures in all books of the 16th and 17th centuries."

While the practice of liming land probably antidates all records of the practice, nevertheless the idea that an acid condition of the soil is the principle factor involved in the liming of land is of rather recent origin. The early English writers, including Davy, ascribed the main benefits of liming land to its influence on the physical condition of the soil, while Leibig attributed the benefits more to the liberation of alkalies and silica from silicates. In 1849 a most excellent treatise by Johnston on liming of soils made its appearance in Britain. As far as the writer has been able to determine, this is the first time that some other writer than Ruffin has given considerable prominence to the action of lime in neutralizing soil acids.

During the last 15 to 20 years of his life, Edmund Ruffin spent much of his time in the discussion of political and economic problems. He was a strong advocate of slavery and fired the first gun at Fort Sumter which precipitated the Civil War. He took an active part in several battles of the Civil War, and shortly after Lee's surrender, at the age of 71, feeling that he was now a man without a country, and too old and weary to be other than a burden to his children, he with stern logic, caused a shot to ring out in order that he might join his comrades who died in battle for a lost cause.

Unfortunately, due to the confusion and disorganization wrought by the Civil War, Ruffin's writings relative to the use of calcareous manures were largely forgotten and lost. The practice of liming, as far as the South is concerned, seems to have largely ended for the time being with the passing of Ruffin. It remained for H. J. Wheeler in the closing years of the 19th century to revive the idea of the general prevalence of acidity in upland mineral soils. By this time, the use of litmus paper for the testing of soils had come into use, and Wheeler, by means of this test, was able to demonstrate positively that many upland mineral soils are distinctly acid and need lime. This was the beginning of a sustained appreciation in this country of the need and value of lime in agriculture.

Over 100 years have passed since Edmund Ruffin through painstaking work and brilliant scientific achievement concluded that upland mineral soils in the humid region often need lime because they are acid, and nearly 50 years have passed since H. J. Wheeler gave positive demonstration to the general prevalence of soil acidity in upland mineral soils of the humid region, and still today, we are applying only a small fraction of the lime to soils that we should. Moreover, today we have tests of considerable refinement for determining the lime needs of soils; lime or marl has been located in nearly every section of the country where liming is needed; highly efficient machinery has been devised for grinding limestone and digging marl; power for operating this machinery is abundant, facilities for transporting the lime to the farm where needed have been developed beyond the fondest hopes of 25 years ago; and finally we have data almost without end showing that the use of lime is fundamental in the humid region to the growth of legumes to nitrogen fixation, to a

favorable availability of soil phosphates, and finally to soil conservation itself. We ride about the country and pass through sections where the eye meets out-crops of limestone in every direction, but alas, due principally to an acid condition of the soil, there are no fields of alfalfa, sweet clover, or other high grade legumes which are so necessary for the creation of a land of "milk and honey".

What is the answer to our dilemma? In a recent article the speaker wrote as follows:[7]

> Why did Kentucky, in 1936, use the equivalent of 124 pounds of lime oxide per acre of crop land and Tennessee only 8½ pounds, and similarly, in the same year, Wisconsin 64 pounds and Michigan only 14 pounds? The climate, need of lime, and natural supplies of lime in the pairs of States compared are quite similar. All of these States have extension services which for a long time have been offering information on the subject through demonstrations, publications, and lectures. Evidently that method alone will not do the job. Until the extension services are able to form some connection with a large-scale organization, either private or governmental, that can be depended upon to furnish the farmer this basic and fundamental soil-building material—lime—at a reasonably low price, or some other equally effective method is found and adopted, permanent soil improvement and soil conservation will remain, to a large degree, "a pot of gold at the end of the rainbow".

Cheap lime for short periods made possible by emergency measures will alone, however, not bring about permanently the kind of a liming program that is needed. The agronomists must do their part. The agronomists must take a positive stand. The agronomists must put soil science to work. They must speak in terms of the general rule rather than in terms of the exception. Too often in the past when the farmer has asked—point blank—"will it pay me to use lime?", the agronomist has retreated to his first-line trenches consisting of a camouflage of garbled scientific or other high-sounding "triple-threat" words, something like this—"Well, you know the soil is a complicated physico-chemico-biologico system made up of mineral and organic material some of which is in colloidal condition, and all of which is infested or populated with myriads of both beneficial and detrimental organisms too small to see. Just what lime will do to these colloids and organisms, I am not quite sure. It might cause what the soil biologist now calls 'a sit down strike' on the part of the organisms, or what the soil chemist calls 'a slow-up strike' on the part of the soil colloids. I tell you what you do. Get a few bushels of lime and spread it on a few square rods of your field, and then if the crop increase is sufficient to pay for the lime and leave a profit, then it will pay you to use lime."

After the agronomist has effected this retreat, what does the farmer do? He also retreats and does exactly what you would do under similar circumstances, namely, he does as in the past, he does not use lime.

How should the agronomist meet a situation fraught with a few special or exceptional cases? Here is Ruffin's answer:[8]

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[7]U. S. Yearbook of Agriculture, page 564. 1938.
[8]Calcareous Manures, ed. 2, page 53. 1832.

"There are many practices universally admitted to be beneficial—yet there are none, which are not found sometimes, useless or hurtful, on account of some other attendant circumstance, which was not expected, and perhaps not discovered. Every application of calcareous manures to soil, is a chemical operation on a great scale: decompositions and new combinations are produced, and in a manner generally conforming to the operators expectations. But other and unknown agents may sometimes have a share in the process, and thus cause unlooked for results. Such differences between practice and theory have sometimes occurred in my use of calcareous manures (as may be observed in some of the reported experiments) but they have neither been frequent, uniform, nor important."

And again quoting from Avery, page 63, here is a sample of what Ruffin accomplished 100 years ago, without any expense to the taxpayer, by preaching the philosophy of the rule rather than the philosophy of the exception.

. . "From 1838 to 1850 the land values of tidewater Virginia increased by over seventeen millions of dollars, and one estimate placed the total increase from the application of marl, after 1820, at over thirty millions. One writer, evidently carried away by his own eloquence, declared that 'Mother earth has changed her face, and . . . her constitution under the healing influence of this salutary medicament, and now presents an appearance as different from her former self, as the healthy and robust man from the lingering and hectic victim of consumption.' 'Verdant fields,' 'luxuriant clover,' and 'abundant harvests' had taken the place of 'broom-straw and poverty grass,' while a poor, thin, and stunted vegetation had 'disappeared.'"

Farmers and even agronomists often say that liming of land is too expensive. Well, how expensive is it? Since a ton of ground limestone, costing in some North Central States approximately $2 will balance this loss for a period of 5 to 10 years, the annual cost per acre becomes 20 to 40 cents. Data from experiments and demonstrations are at hand, almost without end, showing that this cost is insignificant compared to the increased production and the soil improvement that result.

And here again is what Ruffin says relative to the cost of liming land:[9]

"We never calculate the cost of any old practice. We are content to clear wood-land that afterwards will not pay for the expense of tillage . . . But let any new practice be proposed, and then every one begins to count its cost—and on such erroneous premises, that if applied to every kind of farm labor, the estimate would prove that the most fertile land known, could scarcely defray the expenses of its cultivation."

In developing the subject of my talk this evening, I have spoken largely of matters pertaining to liming of land. This method of approach was adopted because that phase of the subject has the richest historical background. What has just been said relative to the agronomists duty in promoting the use of lime applies also to the use of fertilizers, to the furthering of soil conservation, and the adoption of

[9] *Ibid*, page 61.

proper land use programs. We agronomists must all adopt a more incisive and positive attitude in promoting sound and practical programs of soil management.

Before closing, I wish to speak of one more phase of the subject, namely, that having to do with soil testing and the use of fertilizers. I believe it is safe to say that soil and lime testing, crude as it was, is what made possible Ruffin's monumental work in the field of soil acidity, liming, and soil management. During the early years of the 19th century, soil testing was well on its way to becoming a powerful tool in diagnosing the needs of sick soils, as is evidenced by the following quotations:

In 1813, Sir Humphry Davy wrote in his "Elements of Agricultural Chemistry", as follows:

> "If land be unproductive, and a system of ameliorating it is to be attempted, the sure method of obtaining the object is by determining the cause of its sterility, which must necessarily depend upon some defect in the constitution of the soil, which may be easily discovered by chemical analysis."

Fifty-two years later, Dr. August Voelcker[10] wrote as follows:

> "There was a time when I thought, with many other young chemists, that soil-analyses would do everything for the farmer, three or four years of further experience and hard study rather inclined me to side with those men who consider that they are of no practical utility whatever; and now, after eighteen years of continued occupation with chemico-agricultural pursuits and, I trust, with more matured judgment, I have come to the conclusion that there is hardly any subject so full of practical interest to the farmer as that of the chemistry of soils,—the longer and more minutely soil-investigations are carried on by competent men, the greater, I am convinced, will be their practical utility."

Following these early successful attempts at soil testing, there developed during the latter years of the 19th century, a school of thought which held that practically no information of value relative to the lime and fertilizer needs of a soil can be obtained by means of soils tests. This thought arose largely, I believe, because too much was expected at once of a tool in its early years of development, when too little was known of the forms in which plant nutrients exist in soils, of how the readily available constituents may be extracted and determined easily, and finally of the influence of secondary factors such as the minor plant nutrients. Unfortunately this thought still persists in the minds of many agronomists. If soil testing was practicable in Davy's, Ruffin's, and Voelcker's time, it should be even more practicable today when so much more is known relative to the many factors involved.

Following the abandonment of soil testing, for the most part, there developed a mania during the first quarter of the 20th century for the establishment of long-time field experiments. The speaker would not have you think that he does not believe in field experiments and field demonstrations. These field experiments are useful and necessary in establishing sound general principles of soil management. That is, principles, which can only be established by noting the

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[10]See footnote 6, page 129.

influence of specific treatments over a long period of years. They are not adapted, however, for determining the lime and fertilizer needs of a specific soil because these needs vary from field to field on the same farm and even in different parts of the same field. Many field demonstrations are of course needed to help convince farmers of the value of certain practices.

I do not wish to leave the impression that I believe chemical soil tests are infallible. They are, of course, not. However, after 25 years of continuous experience with soil tests, I am convinced that with further study and improvement they will in time be generally used by all agronomists in diagnosing the lime and fertilizer needs of soils devoted to practical agriculture. I envisage a time in the near future when conditions and the supply of plant nutrients in soils devoted to intensive culture will be controlled by means of tests, much like similar matters are controlled in a chemical factory. Then, and only then, can we say that we are putting chemical soil science fully to work in a practical way. In the case of long-time field experiments, soil tests should be applied, from time to time, to determine the influence of any specific treatment on the level of fertility. The results of these soil tests may in certain cases suggest a change in the rate of lime or fertilizer application so as to keep the experiment on a practical basis. Similarly, in practical farming, soil tests serve as an indispensable guide in telling whether or not the returns to a soil are meeting the removal under a specific system of fertilization and cropping.

Some agronomists become greatly disturbed when fertilizer applied on the basis of soil tests does not give sufficient crop increase the first year to pay for the fertilizer. They seem to forget the all-important long time benefit, namely, that of maintenance of soil fertility which is the backbone of soil conservation, for, fertile soils soon produce a protective cover of vegetation, which, for the most part, is the best preventive of soil erosion.

It is the duty of all agronomists to preach the doctrine that the major plant nutrient elements removed from the soil by crops must be returned, pound for pound, in the form of crop residues, animal manure, or commercial fertilizers, if soil fertility is to be maintained. Any other policy has in the past led to and will in the future lead to, first, soil depletion, then, soil destruction by erosion, and finally, economic ruin. To take more out of a soil than is returned, is as certain to deplete a soil in time as the removal of money from a checking account at a greater rate than its return is of putting the checking account "in the red".

Can farmers be sold on the philosophy of returning as much to the soil as is removed? This philosophy is so simple and so sound that farmers can be induced to accept it more easily than some of the make-shift or stop-gap philosophies. During the early years of the present century, Dr. C. G. Hopkins of Illinois preached this philosophy in a positive manner, and, in a short time, sold it so thoroughly that today, 20 years after his passing, many farmers because of his personal influence are still following it.

In general, what policy do many agronomists follow relative to this matter? I size it up about as follows: As long as crop yields are

fairly good and lime and fertilizer do not produce striking results, the farmer is told that the addition of lime and fertilizer is not urgent or needed. Thereupon the farmer spends his spare cash for farm machinery, automobiles, and even speculative securities. Time moves on, and crop yields decline, as they must, and reach a lower than cost of production level, even before the arrival of the impending economic depression. Then the depression breaks with all of its fury, and the farmer aged and weary retires and bequeaths to his son the farm, but, without the soil, without any capital, and without a legacy of information and training relative to maintenance of soil fertility and soil conservation. Under these circumstances, only an Edmund Ruffin succeeds. Unfortunately, Edmund Ruffins are not born everyday, and thus, in many cases it becomes necessary for the government to rehabilitate both the farm and the farmer.

Will this cycle of soil depletion and agricultural desolation be repeated, over and over, indefinitely? If the answer is to be no, then it will be necessary for the agronomist not only to take soil science from the sequestered cloister of the laboratory and hitch it to the plow, but also to go forth preaching a positive and realistic program of soil management and conservation as Edmund Ruffin did over 100 years ago.

(N.B. In view of requests from several sources for an opportunity to obtain a supply of reprints of this paper, the type will be held until about January 15. Orders should be placed with the Editor as soon as possible.)

THE UTILIZATION OF WATER BY ALFALFA (*MEDICAGO SATIVA*) AND BY BLUEGRASS (*POA PRATENSIS*) IN RELATION TO MANAGERIAL TREATMENTS[1]

V. G. Sprague and L. F. Graber[2]

THE responses of alfalfa and bluegrass to deficits in rainfall are highly variable under field conditions. Differences in soil fertility, topography, exposure, evaporational losses, and other interacting factors, cause some bluegrass pastures to remain green much longer during periods of drought than others immediately adjacent. From field observations it would appear that differences in grazing management also may be a highly significant cause of such variations.

The stage of growth at which alfalfa is cut during periods of drought may hasten or retard recovery. In dry seasons, cutting at the early bud stage will usually provide a more immediate recovery than a cutting delayed until near the full bloom stage. However, when drought continues, the more immediate resumption of the growth of alfalfa with early cutting is not usually of practical significance. Moreover, with ample rainfall after cutting at or near full bloom recovery is prompt, except for some varieties of inherent slow recovery such as the Ladak, and the growth is usually more productive in Wisconsin, as recently reported by Graber and Sprague (4).[3]

The purpose of this experiment has been to determine if such variable field responses of bluegrass and alfalfa to moisture deficits may be, in part, a matter of difference in water utilization resulting from variations in managerial treatments of top growth and variations in nutritional levels. The designation "water requirement" as used in this paper refers to the ratio of the amount of water utilized by a plant to the dry matter produced by the plant exclusive of the subterranean parts.

REVIEW OF LITERATURE

Much experimental work has been done on water utilization of plants. As early as 1850, Lawes (7) first demonstrated the effect of fertilizers in lowering the water requirements of plants. Later, Wilfarth and Wimmer (15), Wimmer (16), Widstoe (14), and Leather (8) obtained similar results. Kiesselbach (6) reported in 1916 that while the total water utilized by corn increased 106.7% with increasing levels of fertility, the water requirement of the plants decreased 42.6%. On the basis of the accumulative increments in units of dry matter, water was used more efficiently by plants grown on soils with higher fertility levels.

Some of the evidence on water utilization is rather conflicting. Von Seelhorst (12) in 1910, working with grasses, showed that the water requirement of cultures harvested four times during the summer months was greater than those harvested three times. More recently, Schwarz (11), after a study of the water requirement

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[3]Figures in parenthesis refer to "Literature Cited", p. 996.

of several grasses, concluded that increased yields, in general, were associated with increased utilization of water but with a decreased water requirement and that the date of cutting played a decided rôle in the economy of water.

Richardson and Trumble (10), working with several pasture plants, reported in 1936 that fertilizers, including nitrogen and phosphorus, decreased the transpiration ratio by increasing the dry matter yield of plants and that defoliation either decreased the transpiration ratio or made no change in it.

Briggs and Shantz (1) measured the water utilization of Grimm alfalfa at Akron, Colorado, during three periods, *viz.*, May 24 to July 26, July 26 to September 6, and September 6 to November 4, 1912, the second period being the hottest part of the growing season. One series of alfalfa was cut three times at hay stages, once on July 26, once on September 6, and once on November 4. The water requirement was 600 for the first period, 853 for the second period, and 421 for the third period. The other series was cut three times on the same dates but during the second period the alfalfa was given five additional clippings on August 3, 10, 17, 24, and 31 to simulate grazing during hot weather. With this treatment the water requirement was 615 for the first period, 975 for the second period, and 479 for the third period. Under both treatments there was a marked rise in the water requirement of the alfalfa during the hot period, although the rise was less with the alfalfa clipped frequently.

Dillman (3) conducted very extensive trials (1912–22) on the water utilization of a large number of agronomic plants under conditions of the region of the Northern Great Plains. He found a wide range in the water requirements of different species varying from 224 for Russian thistle (*Salsola* spp.) to 1,183 for western wheat grass (*Agropyron* spp.). There was considerable variability in the water requirements of a given species, dependent upon seasonal conditions. For example, with Kubanka (Durum) wheat, the water requirements were low when the evaporational rate was low and the moisture supply was abundant; and conversely, when the water supply was low and the evaporational rate was high, the yields were small and the water requirements were high. Dillman found that the rate of water utilization increased rapidly as the plants reached their maximum growth and that field crops use very little water during their early stages of growth. When Grimm alfalfa was cut twice after it had matured seed, the water requirement was 28% greater than if cut twice in the early bloom stage of growth and when cut more frequently at intervals of two weeks the water requirement was still further reduced.

The influence of rust diseases on the water economy of cereals has been studied by such workers as Murphy (9), Bever (2), Weiss (13), and Johnston and Miller (5). In general, they have found marked increases in the water requirements of infected plants and that the longer the period of association of host and parasite, the greater was the increase in the water requirement of the host plant.

EXPERIMENTAL PROCEDURE

To study water utilization from the standpoint of management and nutritional treatments, pure cultures were used of two of Wisconsin's most important forage plants—alfalfa (*Medicago sativa*), which is primarily used for hay but is fast becoming increasingly important as dry-weather pasture, and Kentucky bluegrass (*Poa pratensis*), the dominant species of the permanent pasture area.

The trials were conducted in a greenhouse at Madison, Wisconsin. All plants were grown in iron boxes 6 x 8 inches and 12 inches deep filled with a weighed

amount of soil composited from two-thirds Miami silt loam and one-third quartz sand which were well mixed with enough lime, phosphate, and potash added to provide an optimum status of mineral nutrition. On September 8, 1934, seven months before the actual treatments were begun, 96 six-months-old high carbohydrate Turkistan alfalfa plants were dug from the field. The tops were trimmed to 1 inch above the crown and the roots were cut to a uniform length of 6 inches before transplanting four into each of the containers. These boxes were fitted with galvanized iron covers which lay tightly against the soil. Four holes 1½ inches in diameter were cut in each cover where the alfalfa roots were transplanted. The space around the roots was covered with soft wax and the joints at the edges of the iron cover and box were also sealed.

On the same date six vigorous rhizomes of Kentucky bluegrass trimmed to include four nodes were transplanted from the field into each of 24 similar boxes. The soil surface was covered with sheet iron similar to the alfalfa series except that three rectangular openings 1 x 6 inches were cut in the covers. The rhizomes were planted in the soil beneath these openings. The iron cover was sealed with soft wax only around the edges of the containers. The rectangular openings were left uncovered. The amount of water lost from these exposed soil surfaces by evaporation was not determined but due consideration for such errors in the bluegrass cultures will be given in the interpretation of the results.

Water was introduced into each culture by means of L-shaped ¾-inch glass tubes with numerous holes blown through the sides. They extended to the bottom of the iron container where a layer of quartz sand had been provided for a uniform distribution of water throughout the culture. Before transplanting, the containers with soil, sand, and glass tubes were weighed individually and 700 cc of water were added. This provided a moist soil with about 18% moisture which was estimated to be about optimum for the growth of the plants. Each culture weighed approximately 14 kg when ready to be planted. An attempt was made to maintain the water content of the soil at an optimum for the growth of the plants by weighing the cultures every one or two days to make certain all cultures were equally well supplied with water. Even though the area for subterranean growth was limited the plants had full opportunity to grow without the stress of moisture deficits. A fairly uniform distribution of roots in the soil at the close of the experiment indicated that the moisture had not been unduly localized.

Both alfalfa and bluegrass cultures were given favorable conditions to establish themselves for 7 months (after September 8) during fall, winter, and early spring. The top growth of all the cultures was cut down to a ½-inch level on April 9 and the various cutting and fertility treatments were begun at this time.

The experiment included a high-carbohydrate (+CHO) series, simulating deferred grazing or cutting, and a low-carbohydrate (—CHO) series simulating close continuous grazing, in combination with a high-nitrogen (+N) series and a low-nitrogen (—N) series. Each treatment applied to the alfalfa and to the bluegrass was replicated with six cultures. The variable factors may be outlined schematically as follows:

$$\text{Alfalfa}\left\{\begin{array}{l} +\text{CHO}\left\{\begin{array}{l} +\text{N} \\ -\text{N} \end{array}\right. \\ -\text{CHO}\left\{\begin{array}{l} +\text{N} \\ -\text{N} \end{array}\right. \end{array}\right. \qquad \begin{array}{c}\text{Kentucky}\\ \text{bluegrass}\end{array}\left\{\begin{array}{l} +\text{CHO}\left\{\begin{array}{l} +\text{N} \\ -\text{N} \end{array}\right. \\ -\text{CHO}\left\{\begin{array}{l} +\text{N} \\ -\text{N} \end{array}\right. \end{array}\right.$$

The +N treatments were effected by three applications of ammonium nitrate in solution on April 2 and 16 and on May 4 at the rate of 70 pounds of N_2 per acre for each application. The —N cultures received no nitrogen fertilizer. On April 23, 600 pounds per acre of monocalcium phosphate ($CaHPO_4$) and 300 pounds per acre of potassium sulfate (K_2SO_4) were added in water solution to all cultures in the experiment to make certain that a lack of phosphate and potash would not limit growth.

The alfalfa plants and the rhizomes of bluegrass taken from the field and transplanted on September 8 made a healthy vigorous growth becoming well rooted with large accumulations of reserve foods after 7 months of uninterrupted growth. At the end of the period (April 9) the alfalfa was in full bloom and the bluegrass had produced a dense growth of long dark green leaves with all the external evidence of ample food storage. On April 9, the top growth of all cultures was removed at a ½-inch level from the soil surface.

To simulate a deferred grazing plan, cultures of alfalfa and bluegrass were allowed to grow for 65 days (from April 9 to June 13) without cutting. During the early part of this period the plants grew in part at the expense of previously stored foods, but during the latter portion of the period reserve foods accumulated in great abundance, therefore, they shall be referred to as the high-reserve (+CHO) cultures. Half of these cultures (+N) were given three applications of ammonium nitrate (NH_4NO_3) at the rate of 70 pounds of N_2 per acre each and the remainder were not fertilized.

To simulate continuous grazing (—CHO), portions of the top growth were removed at weekly intervals from April 9 to June 13. The bluegrass was cut back to a ½-inch level above the soil surface and the alfalfa was removed at about 2½ inches above the soil surface, a taller remnant of the photosynthetic area being required to avoid a lethal degree of reduction of reserve foods than of bluegrass.

The cutting treatments of both the alfalfa and bluegrass were carried on in two periods. During the first period, from April 9 to June 13, the water utilized and the dry matter (oven-dry basis) produced with weekly clippings of plants high in reserves and grown under high and low nitrogen supplies were recorded. Similar records were taken on the series which was not cut until June 13. This made it possible to compare the water utilized and dry matter produced under the two levels of nitrogen with two cutting treatments.

The second period was that of recovery. It extended from June 14 to July 18 (35 days) during which time all the plants of bluegrass and alfalfa were allowed to grow without cutting or other treatments until July 18. A measure of water utilized and the dry matter produced during this period provided a measure of the residual effects of the previous cutting and fertility treatments on water utilization.

DAILY RATES OF WATER UTILIZATION IN RELATION TO TOP GROWTH

The daily use of water by alfalfa from April 9 to June 13 varied widely in accordance with accumulations of top growth. All cultures responded, more or less, to variable temperature and light conditions in the greenhouse, but such responses were not studied. Where the top growth was not interrupted by cuttings (+CHO) the water utilization was low, ranging between 119 and 200 grams per day (Fig. 1) during the early vegetative stages, but increased markedly

from 200 grams to 365 grams per day when the increments of accumulated top growth became very large. With weekly clippings of alfalfa at a 2½-inch level, the daily rate of water utilization was very low (65 to 167 grams) and was rather constant for the entire period of April 9 to June 13, tending only to rise at the forepart of this period and to decline at the latter part. Applications of nitrogen caused but little difference in the daily rate of water utilization with either the high (+CHO) or low (—CHO) reserve treatments of

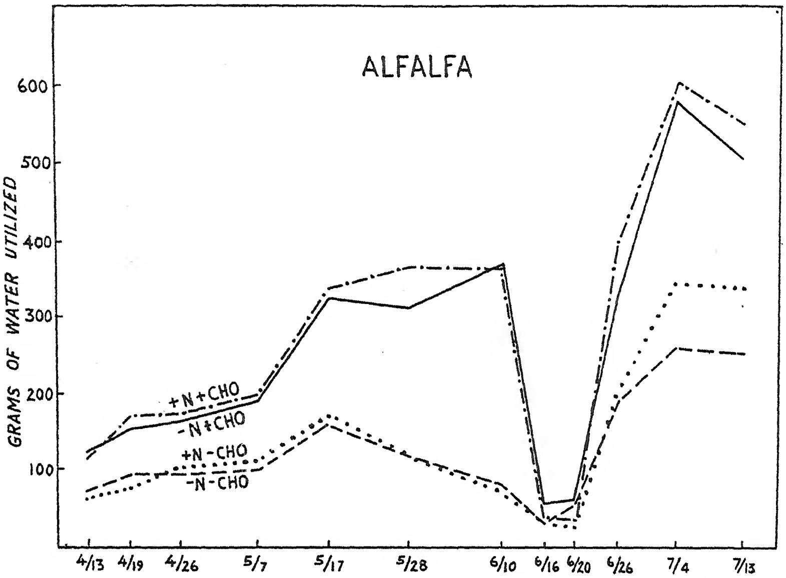

FIG. 1.—Average number of grams of water utilized per day by the alfalfa cultures during the periods represented by their midpoints. All cultures were cut June 13 and allowed to recover without further defoliation. The precipitate reduction in water utilization of the high-reserve plants between the midpoints of June 10 and 16 was due to defoliation on June 13.

alfalfa. Apparently, nitrogen-fixation of the —N alfalfa was sufficient to offset, to a large extent, the influence of nitrogen added in large amounts as ammonium nitrate to the +N cultures.

Nitrogen greatly enhanced the growth of the high-reserve (+CHO) bluegrass and the daily rate of water utilization (Fig. 2) increased from an average of 75 grams in the early vegetative stages to a maximum of 305 grams per day when accumulations of green top growth were greatest. Without nitrogen, the daily rate of water utilization also increased with the increase in photosynthetic area, but the daily rate was much lower and the range (77 to 170 grams) was narrower. Weekly removals of top growth at a ½-inch level not only reduced the daily rate of water utilization still further (53 to 93 grams), but it was quite constant during the entire period of April 9 to June 13. Nitrogen had but very little effect on the daily rate of water utilization of bluegrass given weekly clippings.

TOTAL DRY MATTER PRODUCED AND WATER UTILIZED

The total dry matter (in grams) produced and the total amount of water (in grams) utilized from April 9 to June 13 are given in Table 1. When alfalfa and bluegrass were not cut (+CHO) from April 9 to June 13, the production of dry top growth was much greater and particularly the total amount of water utilized in producing it was much greater than prevailed under the system of weekly cuttings (—CHO).

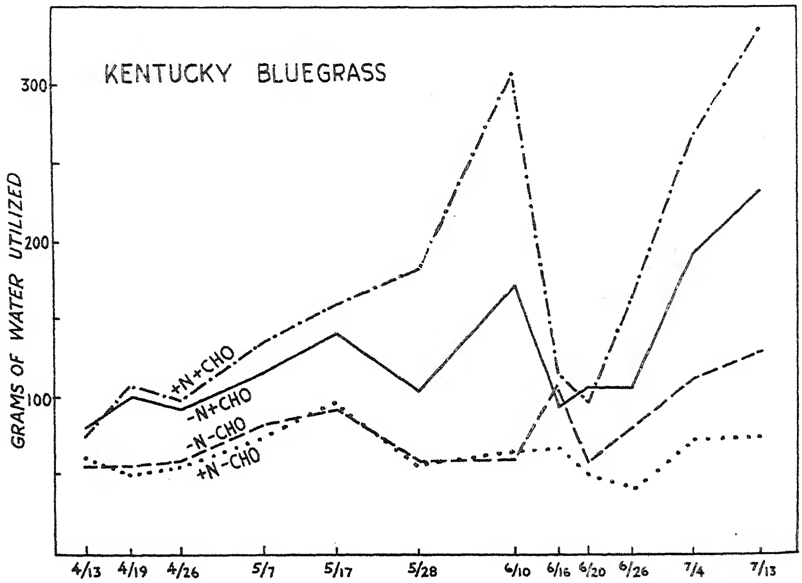

FIG. 2.—Average number of grams of water utilized per day by the Kentucky bluegrass cultures during the periods represented by their midpoints. All cultures were cut June 13 and were allowed to recover without further defoliation. The precipitate reduction in water utilization of high-reserve plants between the midpoints of June 10 and 16 was due to defoliation on June 13.

The ratio between total water consumed and total dry top growth produced for the period of April 9 to June 13 was very much lower with alfalfa clipped frequently (—CHO). The maintenance of a vegetative and succulent growth of alfalfa by clippings at a 2½-inch level lowered the water requirement very materially.

Although the fertilization of alfalfa with nitrogen did not greatly increase the daily rate of water utilization nor the total water utilized, it did lower the water requirements of the high- (+CHO) and low- (—CHO) reserve plants somewhat by increasing the amount of dry matter produced from April 9 to June 13.

Nitrogen fertilization also reduced the water requirement of both the high- (+CHO) and low- (—CHO) reserve bluegrass. It increased the daily rate of water use and the total water utilized of the high- (+CHO) reserve cultures of bluegrass, but the increase in top growth

TABLE 1.—*Total dry matter produced and total water utilized from April 9 to June 13 and from June 14 to July 18.*

Plant	Reserves based on cutting treatments	Nitrogen fertilization	Total H_2O utilized, grams	Total dry matter produced, grams	Ratio H_2O/D.M.
Dry Matter Produced and Water Utilized from April 9 to June 13					
Alfalfa	+CHO	+N	16,267	23.94	679
		—N	15,900	20.62	771
	—CHO	+N	6,767	18.61	364
		—N	6,850	16.91	405
Bluegrass	+CHO	+N	10,533	17.42	605
		—N	7,750	8.65	896
	—CHO	+N	4,466	6.51	686
		—N	4,571	5.76	794
Dry Matter Produced and Water Utilized from June 14 to July 18					
Alfalfa	+CHO	+N	13,583	26.91	505
		—N	12,500	20.56	608
	—CHO	+N	7,883	12.97	608
		—N	6,417	6.97	921
Bluegrass	+CHO	+N	7,716	10.82	713
		—N	5,533	4.06	1,363
	—CHO	+N	2,250	1.16	1,939
		—N	3,400	2.16	1,574

(101%) from fertilization with nitrogen was much greater than the increase (35.9%) in the water utilized to produce it. With the low-reserve (—CHO) cultures, nitrogen fertilization only increased the production of top growth 13%, but the total water utilized was decreased 2.3%.

The weekly clippings (—CHO) of bluegrass at a ½-inch level above the soil surface reduced the food reserves and the productivity of these plants much more than the weekly clippings (—CHO) of alfalfa at a high level of 2½ inches. Thus, weekly clippings (—CHO), from April 9 to June 13, reduced the productivity of fertilized (+N) bluegrass in this period 62% as compared with one cutting (+CHO) on June 13 and 33% as compared with the unfertilized bluegrass (—N). In the case of alfalfa, the concurrent reductions in productivity from weekly clippings were only 22% and 18%, respectively, for the +N and —N cultures.

These and similar comparisons which could be made with respect to subsequent productivity (Table 1) indicate that the reserves of bluegrass were reduced to a much lower status by weekly clippings from April 9 to June 13 than alfalfa clipped at the same frequency but at a much higher level. This matter is discussed because, contrary to the situation with alfalfa, the water requirement of bluegrass was not reduced consistently by the frequent clippings. It appears that the reserves became the limiting factors of growth of the bluegrass and with such and with other limitations of greenhouse culture, the water requirement did not vary widely with respect to the two defoliating treatments (+CHO and —CHO) applied to the bluegrass.

Unfortunately, complete reliance is not to be placed on the data with respect to the water requirements of the clipped (—CHO) bluegrass, since there were unsealed openings in the covers of the bluegrass cultures where the rhizomes were planted and the evaporational losses from these exposed areas were not measured. Perhaps such losses were small and, in some instances, would be comparable, but they would tend to increase the water requirements of the most unproductive (—CHO) cultures. Because the alfalfa cultures were completely sealed, the possibility of such error was eliminated.

WATER UTILIZATION DURING THE FIRST PERIOD OF GROWTH

It would appear from these trials that when alfalfa and bluegrass are kept in a succulent, vegetative state of growth by frequent clippings so that the plastic substances, including previously stored reserves and the immediate photosynthetic products, are being rapidly converted into structural or aplastic materials for growth in expansion, the daily rate of water utilization is relatively low and fairly constant and the total amount of water utilized is greatly reduced. This is much in contrast to the profound increases in daily water use and in total water utilization which prevail when plants approach maturity and accumulate abundant reserves of foods that are stored in the seeds or vegetative parts, or both. With alfalfa, the water requirement was reduced pronouncedly by clippings and conversely it was increased by deferred cutting. Similar results may have been obtained in this trial with bluegrass had it not been clipped so rigorously as to reduce the reserves to a point where they became dominant in the limitation of growth.

It is probable that under field conditions marked accumulations of the top growth of alfalfa and bluegrass resulting from nitrogenous fertilization and from deferred cutting or grazing would greatly increase total water utilization, reducing the reserves of soil moisture as compared with treatments of early and frequent defoliation. Thus, in the advent of drought, alfalfa cut early would have a larger reserve of soil moisture to draw on for prompt recovery and for this same reason bluegrass with early and close grazing could remain green for a longer period during sustained drought. Such field responses have been observed where the differential in moisture supply, due to managerial treatments of the plants, was dominant among other

contributing factors. It is not intended, however, to draw practical conclusions from a greenhouse trial and especially it is not desired to give the impression that early cutting of alfalfa or close early grazing of bluegrass are recommended as antidotes for dry weather. In fact, the authors feel that very early and continuous close grazing of bluegrass (especially when soil fertility is deficient) and early cutting of alfalfa for hay are so hazardous in other respects as to make them generally impractical under the environmental conditions of Wisconsin. The results on water utilization are offered to explain, in part, observed responses in the field rather than to be recommended as the practices which produce them.

RESIDUAL INFLUENCES OF PREVIOUS CUTTING AND NUTRITIONAL TREATMENTS

After June 13 all cultures were permitted to grow without further cutting and fertilization treatments. The top growth was removed completely from each culture on July 18. During these 35 days, the greenhouse temperatures were very high and the high-reserve (+CHO) alfalfa produced a remarkably rapid growth, exceeding or equaling the amount of dry top growth produced during the period of 65 days from April 9 to June 13. On the other hand, the productivity of all cultures of bluegrass was very much less under the high temperatures of June and July than it had been during the previous and cooler period.

Previous clippings (—CHO) reduced the subsequent productivity of the fertilized (+N) alfalfa 52% and of the unfertilized (—N) cultures, 66%. With bluegrass such reductions were 89% (+N) and 47% (—N), respectively.

With high temperatures, the daily rate of water utilization (Fig. 1) of the alfalfa (+CHO) with high reserves, increased with amazing rapidity as did the top growth, varying from 39 grams of water per day in the period about June 15 to 600 grams on July 4 in the case of the +N cultures. The range was quite similar and the rate was only slightly lower for the unfertilized (+CHO) cultures. The daily rate of water utilization of the low-reserve (—CHO +N) alfalfa was much less as was the top growth, ranging from 36 grams to 342 grams of water per day. Previous nitrogen fertilization had a pronounced effect on the growth of the low-reserve (—CHO) alfalfa, increasing the subsequent productivity 86% and increasing the rate of water utilization materially. Nitrogen fixation may well have been decreased by low reserves and high temperatures. Where the reserves were high (+CHO), nitrogen increased subsequent productivity only 31%.

Although previous applications of nitrogen to the high-reserve alfalfa increased subsequent growth 31%, it required only 8.6% more total water to produce this growth. Nitrogen, therefore, reduced the water requirement as it did previous to June 13. Where the reserves of alfalfa were low (—CHO), nitrogen increased the subsequent top growth 86%, but the total water utilized increased only 22.8%. Under all conditions of these trials, nitrogen fertilization reduced the water requirements of alfalfa.

Prior to June 13, the water requirement of alfalfa under a system of weekly defoliations at a 2½-inch level was much lower than with alfalfa not cut until June 13. During recovery, after June 13, the alfalfa was not cut until (July 18) and in this period the water requirement of the low-reserve (—CHO) alfalfa was much greater than the high-reserve (+CHO) alfalfa. It appears that the limitations of nitrogen and food reserves greatly increased the water requirement of the subsequent (June 14 to July 18) growth of the alfalfa.

Probably due to excessive heat in June and July, the low nitrogen (—N) and especially the low-reserve cultures of bluegrass were very unproductive and the water requirement was very high. Nitrogen increased the residual productivity of high-reserve (+CHO) bluegrass 166.5%, but it reduced that of the bluegrass with low reserves 46%. With weekly clippings prior to June 13, at a ½-inch level, the reserves of bluegrass were reduced to a very low level, particularly with the stimulation of nitrogenous fertilization, but all the low-reserve cultures of bluegrass were very unproductive after June 13.

Because of such very meager recovery of bluegrass with low reserves (—CHO) and with high reserves and low nitrogen (+CHO —N), the experimental error resulting from evaporational losses of the unsealed portions of the culture covers was probably too large to warrant full reliance on the determinations of water requirement. This situation was also aggravated by high greenhouse temperatures in June and July. However, giving due allowance for such error, the very high water requirement of the low-reserve cultures of bluegrass during the hot period of July and August would seem to be due to marked limitation of growth resulting from very low reserves. Since, with the previous clipping treatments, nitrogen fertilization had lowered the reserves more than the absence of such treatment, the water requirements of the high-nitrogen low-carbohydrate (+N —CHO) cultures of bluegrass was greater than the low-nitrogen low-carbohydrate (—N —CHO) cultures of bluegrass. Barring this one exception, nitrogen has consistently reduced the water requirement of bluegrass and also of alfalfa.

SUMMARY

A comparison of the water utilization of alfalfa and of Kentucky bluegrass was made under greenhouse control with optimum conditions of moisture and under frequent and deferred cutting treatments, with and without nitrogen fertilization.

The daily rate of water utilization was low in the vegetative stages of growth of alfalfa and bluegrass but increased directly with the rate of top growth accumulation and hence was very high with plants allowed to approach maturity. With weekly clippings which maintained a vegetative state of growth, the daily rate of water utilization was low and quite constant.

Weekly defoliations of well-established, high-reserve cultures of alfalfa greatly reduced the total amount of water utilized and the water requirement during the first 65 days of growth. Such defoliations also reduced the total amount of water utilized by bluegrass, but the water requirements were not greatly affected.

The after effects of the nine weekly defoliations, which lowered the food reserves of alfalfa moderately and the food reserves of the closely clipped bluegrass very severely, were manifested by marked limitations and reductions in subsequent top growth and the total amount of water utilized to produce it, but such previous cutting treatments increased the amount of water needed to produce one unit of dry top growth.

With but one exception, the well-known tendency of nitrogen fertilizations to increase the total water used but to decrease the water required per unit of dry matter produced was clearly evident. It would appear that when growth is definitely limited by reductions in the reserves of bluegrass and alfalfa or by nitrogen deficiencies, the water requirement is increased.

Assuming that the variations in water utilization previously described would apply to comparable treatments of grazing and cutting under field conditions, it is clear that in periods pending drought, early cutting of alfalfa and close early grazing of bluegrass would tend to maintain a greater reserve of moisture in the soil for subsequent growth than would prevail with deferred grazing or cutting. Moisture utilization may, therefore, be a prominent factor in accounting for other than inherent differences in the rate of recovery of the growth of alfalfa with early and deferred cutting and to differences in the rate of recovery of bluegrass with similar contrasts in grazing management. Early cutting and close early grazing are not recommended as antidotes for dry weather but rather to explain, in part, field responses they produce.

LITERATURE CITED

1. Briggs, L. J., and Shantz, H. L. The water requirement of plants. U.S.D.A. B.P.I. Bul. 284. 1913.
2. Bever, Wayne M. Influence of stripe rust on growth, water economy, and yield of wheat and barley. Jour. Agr. Res., 54:375–386. 1937.
3. Dillman, A. C. The water requirement of certain crop plants and weeds in the Northern Great Plains. Jour. Agr. Res., 42:187–238. 1931.
4. Graber, L. F., and Sprague, V. G. The productivity of alfalfa as related to management. Jour. Amer. Soc. Agron., 30:38–54. 1936.
5. Johnston, C. O., and Miller, E. C. Relation of leaf-rust infection to yield, growth and water economy of two varieties of wheat. Jour. Agr. Res., 49: 955–981. 1934.
6. Kiesselbach, T. A. Transpiration as a factor in crop production. Neb. Agr. Exp. Sta. Res. Bul. 6:3–214. 1916.
7. Lawes, J. B. Experimental investigation into the amount of water given off by plants during their growth; especially in relation to the fixation and source of their various constituents. Jour. Hort. Soc. of London, 5:38–63. 1850.
8. Leather, J. W. Water requirement of crops in India. Mem. Dept. Agr., India. Chem. Ser., 1:133–184; 205–281. 1910–11.
9. Murphy, H. C. Effect of crown rust infection on yield and water requirement of oats. Jour. Agr. Res., 50:387–411. 1935.
10. Richardson, A. E. V. and Trumble, H. C. The water requirements of pasture plants. Rpt. Waite Agr. Inst. Univ. Adelaide, 1933–36: 91–106. 1937.
11. Schwarz, R. Investigations on the water requirement of different grasses. (Translated title.) Wiss. Arch. Landw. Abt. A, Arch. Pflanzenbau, 8:276–334. 1932.
12. Seelhorst, Conrad von. Der Wasserverbranch von Wiese and Weide. Jour. für Landwirtschaft, 58: Heft. 1, 83–88. 1910.

13. Weiss, F. The effect of rust infection upon the water requirement of wheat. Jour. Agr. Res., 27:107–118. 1924.

14. Widtsoe, J. A. Irrigation investigations. Factors influencing evaporation and transpiration. Utah Agr. Exp. Sta. Bul. 105. 1909.

15. Wilfarth, Herman and Wimmer, G. Die Wirhung des Kaliums auf das Pflanzenleben nach Vegetationsversuchen mit Kartoffeln, Tabak, Buchweizen, Senf, Zichorien und Hafer. Berlin: Arbeiten, Deutsche Landwirtschafts-Gesellschaft. Heft 68. 1902.

16. Wimmer, G. Nach welchem Gesetzen erfolgt die Kaliaufnahme der Pflanzen aus dem Boden? Berlin: Arbeiten, Deutsche Landwirtschafts-Gesellschaft. Heft 143. 1908.

NEW DISEASE-RESISTANT EARLY OATS FROM A VICTORIA-RICHLAND CROSS[1]

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PRIOR to the introduction of Victoria (C. I. 2401)[3] in 1927, no varieties of oats possessing high resistance to crown rust were available to the plant breeder. The best resistance up to this time was found in some of the Australian varieties, such as Ruakura and Sunrise, and in certain strains of the Green Russian oat, such as Rainbow and Schoolmam. The discovery of the high resistance of Victoria to crown rust in 1929 has served greatly to stimulate interest in breeding to eliminate the destructive effects of this disease in the United States. The introduction of Bond (C.I. 2733) in 1929 made available to breeders another variety with high resistance to many physiologic races of crown rust.

Victoria also is highly resistant to all races of the oat smuts tested, which includes most of those so far collected and identified, while Bond apparently has resistance only to certain races. Since their introduction these varieties have been employed extensively in breeding improved varieties with high resistance to crown rust and smut. Results obtained with a cross of Victoria on Richland are reported in this paper.

A considerable portion of the present oat acreage of the Corn Belt is sown to improved early varieties developed cooperatively by the Iowa Agricultural Experiment Station and the U. S. Dept. of Agriculture. The commercial production of these early varieties, namely, Albion (Iowa 103, C. I. 729), Iowar (C. I. 847), Richland (Iowa 105, C. I. 787), and Iogold (C. I. 2329), has contributed materially to the agricultural wealth of the country. Richland and Iogold have been especially outstanding because of high yield and excellent resistance to stem rust, although lacking resistance to crown rust and to smut. Burnett, Stanton, and Warburton (2),[4] Stanton, Griffee, and Ether-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station, cooperating. Journal Paper No. J-574 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 73. Some data were obtained on the smut resistance of these selections in cooperation with the Idaho Agricultural Experiment Station and the Brooklyn Botanic Garden. Yield data were obtained only in 1937 in cooperation with the Ohio, Indiana, Illinois, Missouri, Nebraska, Michigan, Wisconsin, North Dakota, and Oregon Agricultural Experiment Stations. Received for publication, September 27, 1938.

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[3]Accession number of the Division of Cereal Crops and Diseases, formerly Division of Cereal Investigations.

[4]Figures in parenthesis refer to "Literature Cited", p. 1008.

idge (10). Stanton, Love, and Gaines (11), and Burnett (1) have reported on the development, distribution, and value of these varieties.

Murphy and Stanton (7) reported the introduction of Victoria from Uruguay, South America, and the high resistance of this variety to severe epidemics of crown rust at Ames, Iowa, and Manhattan, Kans., in 1929, and its uniform resistance to the eight physiologic races of crown rust collected throughout the United States in the same year. Stanton and Murphy (12) give further details concerning the breeding and development of Victoria in South America. Murphy (4) found that Victoria was resistant to 33 physiologic races of crown rust collected in the United States, Canada, and Mexico in the 6-year period, 1927–32, and that it was highly resistant in field tests conducted in the principal oat-growing regions of the United States during the period 1929 to 1932. In a later report, Murphy (5) showed that Victoria was resistant to 37 races of crown rust collected in the United States, Canada, and Mexico in the 9-year period, 1927–35, and to all collections of smut used in field and greenhouse experiments at Ames, Iowa, during the same period. Murphy and Levine (6) found Victoria susceptible to an apparently new and rare race (No. 41) of crown rust collected in Texas in 1935.

THE VICTORIA-RICHLAND CROSS

Stanton, et al. (13) and Stanton (9) discussed the Victoria×Richland cross (X S1098) and the development of the selections with which this paper is concerned, up to and including the fifth generation. Stanton, et al. (13) also described a second group of selections from the Victoria-Richland cross, tested mainly for disease resistance in the greenhouse at the Arlington Experiment Farm, Arlington, Va., and at Aberdeen, Idaho.

Seed of individual F_5 plants of the Victoria-Richland cross selected from the more promising progenies grown at Ames in 1933 was sown in the greenhouse at Arlington Farm in the fall of 1933. These selections were inoculated with spores of crown and stem rust and with the oat smuts collected in the Corn Belt. A high percentage of them continued to show satisfactory resistance to all these diseases. Seed from the more desirable plants grown in the greenhouse was sown at Ames in the spring of 1934 but failed to germinate owing to the very severe drought that year. Remnant seed from a number of the plants, however, was sown at Aberdeen, Idaho, the same season and among selections from these F_6 progenies were early, small-kerneled types resembling the Richland parent. Certain plants that were especially outstanding for earliness and high tillering capacity have given rise to most of the strains that were advanced to small increase plats at Ames in 1937. These trace back to three F_4 plants which arose from single F_2 and F_3 plants.

No smut infection occurred in any of these progenies inoculated and sown at Aberdeen in 1934. Seed of 48 of the more vigorous F_7 plants were sown in single 15-foot rows at Ames in 1935. These new rust- and smut-resistant strains were unusually promising in yield and were fair to good in grain quality. All of the 48 lines were grown in duplicated 15-foot rows at Ames in 1936 and 12 of the best were grown also in duplicated 4-row (15-foot) plats. Similar plantings of these same selections also were made at Kanawha in northern Iowa. Ten of the highest yielding selections were grown in field plats at Ames in 1937 and others were con-

tinued in nursery tests. Certain selections also were sent to experiment stations in other states for testing. Some of the newer re-selections may prove superior in straw characters and grain quality to the strains being grown in field plats.

METHODS OF INOCULATION

CROWN AND STEM RUST

Urediospore suspensions of physiologic races of crown and stem rusts, common throughout the North Central states, were injected hypodermically into susceptible Markton plants in border and alley rows. The inoculations were made when the plants were 8 to 10 inches high and resulted in their complete infection in the border and alley rows when they reached the boot stage. The rust, disseminated from these infected rows, combined with the natural infection, was sufficient in each year, except 1934, to produce a maximum infection on all susceptible plants in the 5-foot rows of the hybrid nursery.

No attempt was made to initiate epidemics of either crown or stem rust in the rod-row and 1/20-acre plats because of the adverse effect it might have on the yield of the check varieties. Rust infection resulting from natural dissemination, particularly of crown rust in 1935, usually was sufficiently heavy, however, to allow accurate observations of the relative resistance of the selections and their parent varieties.

SMUTS

Tests for resistance to the smuts of oats were made in both field and greenhouse beginning with the F_3 generation of most families. In nearly all years inoculum was used that had been collected from commercial fields in the Corn Belt. Usually spores from plants smutted in the previous generation were added to this inoculum to make sure that the races commonly found in the Corn Belt, as well as any existing unidentified races, might be present. No effort was made to separate the two smut species, although there usually was a preponderance of loose smut (*Ustilago avenae*) in the collections, as a high percentage of the smut occurring in the more humid regions of the United States is of this species.

The hulls or glumes were removed from all seed (caryopses) before inoculation with smut spores. Usually the seeds were dusted with smut spores by placing a small quantity of the inoculum in the seed envelope and then shaking until all seeds were blackened. New smut inoculum was used each year. The temperature in the greenhouse was maintained at about 75°F for 6 or 7 days immediately following seeding to favor the germination of the smut spores.

At harvest all plants showing any smut infection were discarded. Usually smut-free plants lacking vigor, earliness, or desirable grain characters also were discarded.

EXPERIMENTAL DATA

RUST AND SMUT RESISTANCE

In general, the selections were so consistently free from rust and smut under field conditions in 1935 and 1936 that few detailed notes could be recorded. Of the 48 selections grown in 15-foot rows at Ames in 1935, 40 had an infection coefficient of 2 and 8 a coefficient of 3 for crown rust, in contrast with 60 for the susceptible Richland parent variety. All the selections were highly resistant to stem rust, with an infection coefficient of 1 as contrasted with 50 for the Victoria parent.

Selection 550 was very susceptible to halo blight in 1935. There was no marked natural epidemic of either crown or stem rust at Ames or Kanawha in 1936, and as a consequence little or no rust was present even on the susceptible Markton check, except in plantings subjected to artificial inoculation. At both Ames and Kanawha not a single panicle infected with smut was observed in any of the 48 selections grown in replicated nursery rows. However, there was a considerable number of smutted panicles in nearly all check rows of Iogold.

In 1937, 24 of the Victoria × Richland selections were grown in disease nurseries at Ames and Kanawha, Iowa. Sixty hulled (dehulled) kernels of each selection and check variety were dusted with smut spores and space planted in rod rows. The smut used for the test at Ames was obtained from a composite lot of smutted panicles collected from the oat-breeding nursery at Ames in 1936, while, at Kanawha, a collection obtained from a local farmer's field in 1936 was used. Crown rust infection was initiated at Ames by hypodermic inoculation of Markton plants growing in border rows. The stem-rust infection at both locations and the crown rust at Kanawha resulted from natural dissemination. The reaction of the 24 selections and their parent varieties, and of the Iogold check, to smut and both rusts at Ames and Kanawha in 1937 is shown in Table 1.

Except for one plant in selection 508 at Ames, all of the 24 Victoria × Richland selections and the Victoria parent were entirely free from smut infection at Ames and Kanawha in 1937. The Richland parent and a sister selection, Iogold, were approximately 50% infected.

The 24 selections showed some infection with crown rust; however, this infection was of a type that indicated satisfactory resistance and the percentage was low. As a result the average infection coefficient was approximately one-tenth that of the susceptible Richland and Iogold varieties. Field and greenhouse results indicate that these Victoria × Richland selections, and the Victoria parent, have sufficient resistance to all except one of the 46 physiologic races of crown rust known to occur in the United States to afford adequate protection against any ordinary epidemic that might occur. This race, No. 41, apparently is a rare one, collected only in 1935.

The Richland type of resistance to stem rust, which these selections possess, has been sufficient to afford adequate protection from stem rust throughout the Corn Belt during the past 20 years, although two physiologic races of stem rust (Nos. 8 and 10) to which Richland is susceptible, have been known to occur in the United States occasionally during this period. Levine and Smith (3) report, however, that the oat-stem-rust epidemics in the United States during the 15-year period 1921–35 were due almost entirely to the widespread distribution of races Nos. 2 and 5, which constituted 98% of the total isolates identified during that period. Richland and the Victoria-Richland hybrids are extremely resistant to races Nos. 2 and 5 both in the seedling and adult stages.

TABLE 1.—*Reaction to smut, crown rust, and stem rust of 24 Victoria × Richland selections grown at Ames and Kanawha, Iowa, in 1937 in comparison with the Victoria, Richland, and Iogold varieties.*

C. I. No.	Plant sel. No.	Reaction to smut, crown rust, and stem rust*					
		Ames			Kanawha		
		Smut %	Rust		Smut %	Rust	
			Crown, coeff.	Stem, coeff.		Crown, coeff.	Stem, coeff.
2329	(Iogold)	58	75	0	43	30	0
——	501	0	6	0	0	4	0
——	504	0	6	0	0	6	0
3302	506	0	8	0	0	6	0
3303	507	0	8	0	0	6	0
3304	508	3	4	0	0	3	0
3305	509	0	4	0	0	3	0
2329	(Iogold)	45	70	0	54	35	0
3309	517	0	6	0	0	3	0
3310	518	0	6	0	0	3	0
3311	519	0	6	0	0	3	0
3312	520	0	6	0	0	4	0
3313	521	0	6	0	0	3	0
3314	522	0	4	0	0	3	0
3315	526	0	8	0	0	6	0
3316	527	0	6	0	0	6	0
3334	529	0	4	0	0	3	0
2329	(Iogold)	60	75	0	50	40	0
3336	532	0	4	0	0	3	0
3337	543	0	4	0	0	3	0
3338	545	0	4	0	0	3	0
3339	546	0	4	0	0	3	0
3340	550	0	4	0	0	3	0
2329	(Iogold)	64	70	0	47	40	0
2329	(Iogold)	80	65	0	62	30	0
3500	35-419	0	10	0	0	5	0
3501	35-542	0	6	0	0	2	0
3502	35-548	0	8	0	0	4	0
3503	35-609	0	6	0	0	3	0
2329	(Iogold)	72	65	0	63	30	0
787	(Richland)	48	85	0	49	55	0
2401	(Victoria)	0	4	15	0	3	20

*For an explanation of the coefficient of infection of rust, see Murphy (4), page 8.

SMUT RESISTANCE

In the spring of 1937, seed of 16 of the Victoria × Richland selections was sent to Dr. George M. Reed, Brooklyn Botanic Garden, Brooklyn, N. Y., for a re-test of their resistance to the rather large collection of races of the oat smuts available at that institution. Each selection was inoculated with 19 races, including both loose and covered smuts, in accordance with the method devised and used by Reed (8). The results obtained on the reaction of these tester varieties to these races to which the Victoria-Richland selections were completely resistant are presented in Table 2.

TABLE 2.—*Reaction of tester varieties of oats to 19 races of oat smuts to which the Victoria-Richland selections were completely resistant, Brooklyn Botanic Garden, 1937.*

Smut inoculum		Plants infected							
Species and type	Race No.	Hull-less (30)* %	Canadian (119) %	Early Champion (150) %	Gothland (152) %	Monarch (161) %	Kanota (906) %	Red Rustproof (999) %	Fulghum (1000) %
Ustilago avenae—									
Red Rustproof	44	—	35.0	—	—	—	—	17.3	—
	45	—	83.3	—	—	—	—	60.0	—
	47	—	54.5	—	—	—	—	27.2	—
	1	85.0	—	86.9	100.0	0	—	—	—
U. avenae—									
Miscellaneous	26	65.0	—	63.1	0	4.7	—	—	—
	32	100.0	—	68.1	18.1	4.3	—	—	—
	41	66.6	—	95.4	24.0	86.9	—	—	—
	54	61.9	—	71.4	65.2	76.9	—	—	—
	55	85.7	—	100.0	94.1	21.0	—	—	—
U. avenae—									
Fulghum	13	100.0	—	—	—	—	85.0	—	73.6
	18	100.0	—	—	—	—	60.8	—	56.0
U. levis—									
Fulghum	11	—	—	—	—	87.5	—	—	50.0
	12	—	—	—	—	87.5	—	—	45.4
U. levis—									
Miscellaneous	1	85.0	—	87.5	—	100.0	—	—	—
	3	—	—	5.0	—	66.6	—	—	—
	9	83.3	—	76.9	—	81.8	—	—	—
	16	42.8	—	55.5	—	75.0	—	—	—
	19	5.2	—	65.0	—	80.0	—	—	—
	23	47.0	—	76.1	—	91.6	—	—	—

*Special seed numbers for the particular varietal strains used by Reed as host testers in his smut investigations.

The following 16 selections of the Victoria-Richland cross were tested:

C. I. No.	Selection No.	C. I. No.	Selection No.
3301	502	3309	517
3302	506	3310	518
3303	507	3311	519
3304	508	3312	520
3305	509	3313	521
3306	512	3314	522
3307	514	3315	526
3308	516	3317	544

An average of about 20 plants (with a range of from 13 to 25 plants) of each selection and tester variety was grown from seed inoculated

with each of the 19 races of smut. A total of 6,229 plants of the 16 Victoria-Richland selections were grown. One plant of one selection (C. I. 3302), inoculated with race No. 41, was smutted. This plant probably was a rogue. All other Victoria-Richland plants were entirely free from smut, although most of the host tester varieties (Table 2) showed heavy infection when inoculated with the different races of the two smuts. The contrast of their reaction with that of the Victoria-Richland selections is so marked that further comment is unnecessary.

The consistently high resistance of these selections to the oat smuts indicates rather definitely the great value of Victoria as a smut-resistant parent. As Richland is resistant to the races of the oat smuts that attack Fulghum and Red Rustproof, the high resistance of these selections may be due to the bringing together of genes for resistance from both parental varieties. No other group among the numerous hybrid selections tested by the writers in breeding for smut resistance during the past 15 years has been so consistently resistant.

GRAIN YIELD

Limited data on the grain yields of the Victoria-Richland selections were obtained in Iowa at Ames in 1935, 1936, and 1937, and at Kanawha, and also at 10 experiment stations in other states, mostly of the Corn Belt, in 1937. As previously mentioned, 48 selections were first tested for yield at Ames in single 15-foot rows in 1935. These same 48 strains were continued at Ames in 1936, in duplicated 15-foot rows, and a few of the best also were grown in duplicated four-row 15-foot plats. Similar tests of these same selections were made at Kanawha, Iowa, in 1936. In addition, several hundred other selections of the cross were grown in single 15-foot rows at Ames in 1936. A few hundred new panicle selections also were grown in 5-foot rows at Ames for possible isolation of still better lines. Ten of the best selections, as indicated by the results of 1935 and 1936, were grown in 1/20-acre plats at Ames in 1937. However, owing to the fact that in both 1936 and 1937 many of the selections were discarded directly in the field, yield data are available from only a relatively small number. These data from the 20 selections grown three years at Ames and two years at Kanawha are presented in Table 3.

Yields in 1937 at Columbus, Ohio, Lafayette, Ind., Urbana, Ill., Columbia, Mo., Lincoln and North Platte, Nebr., Chatham, Mich., Madison, Wis., Dickinson, N. Dak., and Corvallis, Ore., also are presented in Table 3.

The yield data presented in Table 3 suggest that the Victoria-Richland selections as a group appear to be exceptionally well adapted to the Corn Belt. They have shown marked superiority over the best local standard varieties, particularly at Lafayette, Ind., Urbana, Ill., and Ames, Iowa. They also have shown high yielding ability at Columbia, Mo., and Madison, Wis. The high productiveness of these new selections is indicated by the average yield of the 20 selections grown in 15-foot rows at Ames in 1937. They averaged 96 bushels to the acre as compared with 75.2 bushels for Iogold, a standard early

TABLE 3.—*Annual and average yields of 20 stem-rust-crown-rust and smut resistant selections from the Victoria-Richland cross, and of certain standard varieties as checks grown for one or more years at agricultural experiment stations in the United States, 1935–37.*

C. I. No.	Plant Sel. No.	Acre yield of grain, bushels																					
		Ames, Iowa					Kanawha, Iowa			Average for both Iowa stations	Experiment stations and cooperators in other States—1937 only										Average for all Stations f	Station years	Rank
		1935a	1936b	1937c	Average	Increase plats 1937d	1936e	1937c	Average		Columbus, Ohio, J. B. Park	Lafayette Ind., G. H. Cutler	Urbana, Ill., O. T. Bonnett	Columbia, Mo., B. M. King	Lincoln, Nebr., T. A. Kiesselbach	North Platte, Nebr., Orrin Webster	Chatham, Mich., B. R. Churchill	Madison, Wis., H. L. Shands	Dickinson, N.Dak. R. W. Smith	Corvallis, Ore., D. D. Hill			
—	501	76.0	71.0	92.6	79.9	—	77.0	67.3	72.2	76.8	—	—	—	—	—	—	—	—	4.8	—	64.8	6	15
—	504	63.0	69.0	91.8	74.6	—	89.0	93.0	91.0	81.2	—	—	—	—	—	—	—	—	9.4	—	69.2	6	12
3302	506	98.0	72.0	109.8	93.3	94.4	90.7	93.0	91.9	92.8	58.0	97.9	49.4	72.6	35.3	28.5	12.9	—	9.6	63.0	63.6	14	16
3303	507	67.0	88.0	99.0	84.7	—	90.0	102.0	96.0	89.2	—	—	—	68.0	—	—	—	—	10.4	—	74.9	7	3
3304	508	99.0	75.4	96.4	90.3	96.2	84.0	103.0	93.5	91.6	46.7	105.4	64.3	76.2	30.6	—	19.5	59.8	—	68.4	71.4	13	8
3305	509	89.0	76.0	96.8	87.3	101.6	85.0	102.3	93.7	89.9	49.0	103.7	60.3	65.7	—	—	20.0	66.4	—	62.6	73.1	12	6
3309	517	93.0	78.2	102.6	91.3	107.8	89.0	97.3	93.2	92.1	—	—	—	59.4	—	—	19.5	64.9	—	66.0	74.4	9	4
3310	518	87.0	87.0	93.4	89.1	101.6	79.0	94.3	86.7	88.1	52.2	91.9	61.6	80.8	41.6	—	20.5	63.3	—	63.2	70.4	13	11
3311	519	101.0	78.6	92.2	90.6	88.4	74.0	94.0	84.0	88.0	54.2	87.4	56.1	76.2	32.3	27.2	15.9	59.5	11.2	61.6	61.4	15	19
3312	520	82.0	75.8	107.4	88.4	103.1	84.7	100.7	92.7	90.1	51.0	96.2	58.5	81.2	34.2	—	24.5	62.7	—	67.8	71.3	13	9
3313	521	86.0	78.8	103.2	89.3	98.1	80.3	101.7	91.0	90.0	48.0	98.9	57.4	65.7	29.6	—	—	60.5	—	—	73.6	11	5
3314	522	92.0	78.6	104.2	91.6	95.0	83.7	94.3	89.0	90.6	50.3	97.0	59.1	81.5	33.6	29.5	14.6	55.2	—	58.4	66.6	14	14
3315	526	113.0	73.8	93.8	93.5	—	75.3	95.0	85.2	90.2	54.7	91.7	55.6	86.1	35.8	—	—	67.9	5.6	—	70.7	12	10
3316	527	67.0	73.0	92.4	77.5	91.2	82.7	85.3	84.0	80.1	51.4	94.2	55.6	—	—	—	—	—	—	—	75.2	8	2
3334	529	60.0	64.0	85.0	69.7	—	92.0	57.3	74.7	71.7	57.5	80.7	47.6	—	32.7	—	—	—	8.6	—	58.5	10	20
3336	532	85.0	64.0	89.8	79.6	—	95.0	88.7	91.9	84.5	44.3	102.2	53.0	—	31.5	26.6	—	—	10.0	—	62.7	11	17
3337	543	87.0	70.0	79.2	78.7	—	98.0	90.0	94.0	84.8	55.8	107.7	50.5	—	31.7	—	—	—	6.8	—	67.7	10	13
3338	545	73.0	67.0	89.4	76.5	—	87.0	81.0	84.0	79.5	57.0	82.5	50.7	—	30.3	—	—	—	6.4	—	62.4	10	18
3339	546	104.0	73.0	106.2	94.4	—	89.0	102.7	95.9	95.0	—	91.2	48.9	—	29.7	—	—	—	—	—	80.6	8	1
3340	550	117.0	58.0	94.4	89.8	—	91.0	60.7	75.9	84.2	—	77.5	46.0	—	30.6	—	—	—	—	—	71.9	8	7
No. of selections.....		20	20	20	20	10	20	20	20	20	14	16	16	11	14	4	8	9	10	8	—	—	—
Average....		87.0	73.6	96.0	—	97.7	85.8	90.2	—	—	52.2	94.1	54.7	73.9	32.8	28.0	18.4	62.2	8.3	63.9	—	—	—
Comparative yieldsg		60.5	78.6	75.2	—	84.4	70.7	76.7	—	—	48.6	92.4	48.6	70.6	32.2	23.8	29.5	53.8	12.3	70.8	—	—	—
Check or standard variety used...		Iogold	Iogold	Iogold	—	Richland	Iogold	Iogold	—	—	Franklin	Gopher	Kherson	Columbia	Iogold	Brunker	Iowa 444	State Pride	Gopher	Victory			

a Single 15-foot rows.
b Weighted averages of duplicated 4-row and 2-row plats (15-foot).
c Weighted averages of single 4-row and triplicated 2-row plats (15-foot).
d Single 1/20-acre plats.
e Weighted averages of duplicated and quadruplicated single rows (15-foot).
f Yields from increase plats at Ames in 1937 not included.
g Average of nearest check plats of standard variety.

variety for Iowa. The corresponding yields at Kanawha are 90.2 and 76.7 bushels, respectively. The 10 selections grown in increase plats at Ames in 1937 made the remarkably high average yield of 97.7 bushels as compared with a yield of 84.4 bushels for the Richland check. The one best selection (C. I. 3309) yielded 107.8 bushels an acre, and three other selections of the 10 yielded in excess of 100 bushels. It is believed that the results obtained in this preliminary plat test are indicative of the excellent yielding ability of these new hybrid oats, but further testing is necessary.

The yields of the selections compare favorably with those of standard varieties at some of the other stations. At Columbus, Ohio, the 20 selections grown averaged 3.6 bushels more oats per acre than Franklin. The average for 16 selections at Lafayette, Ind., was 94.1 bushels as compared with 92.4 bushels for Gopher, the check variety. At Urbana, Ill., the average of 16 selections exceeded the Kherson check by 6.1 bushels to the acre. The 11 selections grown at Columbia, Mo., made an average yield of 73.9 bushels as compared with 70.6 for Columbia, a very high-yielding variety now extensively grown in Missouri. At Lincoln, Nebr., the selections on the average only barely exceeded the yield of the Iogold check. Four selections grown at North Platte, Nebr., produced an average yield of 28.0 bushels as compared with 23.8 bushels for Brunker, one of the high-yielding varieties which have been tested for a period of years at that station. Eight selections were tested at Chatham, Mich., but they failed to produce satisfactory yields as compared with Iowa 444, a variety well adapted to that section. It is evident that these selections were somewhat out of their best environment in this northern section. The average acre yield for 10 selections grown at Madison, Wis., is 62.2 bushels, as compared with 53.8 for State Pride, the leading standard early variety for Wisconsin. At Dickinson, N. Dak., the average of 10 selections is 8.3 bushels per acre compared with 12.3 bushels for Gopher. At Corvallis, Ore., these selections as a group were inferior in yield to Victory, a standard midseason variety.

GRAIN QUALITY

Bushel weight or test weight is the standard measure of quality in oats. Weight-per-bushel determinations were obtained on the Victoria × Richland selections in 1936 and 1937 at both Ames and Kanawha. The average bushel weight of all selections grown in the different nursery tests, compared with those of the nearest Iogold checks, are shown in Table 4.

The data of Table 4 show that the Victoria × Richland selections on the average exceeded Iogold by from 2.7 to 4.3 pounds per bushel in the nursery tests in 1936 and 1937 at both stations. The average bushel weights indicate rather conclusively that these selections are decidedly superior in quality to Iogold as well as to most other groups of hybrid selections of early oats under test at Ames.

The 10 Victoria × Richland selections (C. I. 3302, 3304, 3305, 3309 to 3314, inclusive, and 3316) grown in increase plats at Ames in 1937 had an average bushel weight of 32.7 pounds as compared with

TABLE 4.—*Average bushel weight of the Victoria-Richland selections compared with Iogold, grown in nursery plats at Ames and Kanawha, Iowa, in 1936 and 1937.*

Variety	Number of selections	Average bushel weight, lbs.
Ames, 1936		
Victoria×Richland[a]	11	31.8
Iogold (3 checks)	—	27.9
Difference		3.9
Victoria×Richland[b]	20	30.5
Iogold (4 checks)	—	27.8
Difference		2.7
Ames, 1937		
Victoria×Richland	20	28.5
Iogold (4 checks)	—	24.2
Difference		4.3
Kanawha, 1936		
Victoria×Richland[c]	11	26.7
Iogold (3 checks)	—	23.0
Difference		3.7
Victoria×Richland[d]	16	27.2
Iogold (4 checks)	—	24.5
Difference		2.7
Kanawha, 1937		
Victoria×Richland	20	32.6
Iogold (4 checks)	—	29.3
Difference		3.3

[a] 4-row plats.
[b] 2-row plats.
[c] Quadruplicate plats.
[d] Duplicate plats.

28.5 pounds for the Richland checks, a difference of 4.2 pounds. An increase of 3 to 4 pounds to the bushel would add materially to the value of the oat crop in the Corn Belt.

OTHER CHARACTERS

The performance of the Victoria × Richland selections indicates that they are superior to the Iogold and Richland varieties in yield and quality, even where rust and smut were not limiting factors. Apparently, their tolerance to heat and drought, or better adaptation, must be considered. Certain factors on which little tangible information is available, such as resistance to the attacks of soil-borne organisms and minor diseases, may play an important

rôle in the apparent better adaptation of these new hybrid oats. However, further investigation is necessary to evaluate definitely the influence of these factors.

The behavior of the Victoria × Richland selections in the northern latitude of Chatham, Mich., where they failed to grow tall enough and to produce satisfactory yields, may indicate that their range of adaptation is farther south where the climate is warmer.

The data of Table 3 show rather definitely that these selections are evidently well adapted to the central Corn Belt section, where heat and disease are the chief limiting factors in oat production. Limited tests indicate that they also may be adapted to the southern part of the Corn Belt, where strains of Burt and Fulghum are now the leading agricultural varieties.

The performance of the Victoria × Richland selections gives promise of making oats a more productive crop in the Corn Belt. If their high performance is maintained and if now unimportant races of smut and rust, to which these selections are susceptible, do not increase and attack them, one or more of the selections probably will be distributed to farmers in the Corn Belt within the next few years.

SUMMARY

The introduction of Victoria oats from Uruguay by the U. S. Dept. of Agriculture in 1927 made available for breeders a variety with high resistance to crown rust. Later, it was found that Victoria also was highly resistant to the oat smuts.

Victoria has been crossed on many of the best commercial varieties to develop new varieties of oats with high resistance to crown rust and smut. Results with selections obtained from the cross of Victoria on Richland, the latter a high yielding, early oat with high resistance to stem rust and extensively grown in the Corn Belt, are presented here.

Tests in Iowa and other States indicate that, especially under Corn Belt conditions, these selections have a very high yielding ability and high test weight, in addition to their high resistance to the smuts and rusts.

Unless hitherto unimportant races of the smuts and rusts spread and attack these selections, one or more of them probably will be distributed to Corn Belt farmers within the next few years.

LITERATURE CITED

1. BURNETT, L. C. Iogold oats. Iowa Agr. Exp. Sta. Bul. 247:186–198. 1928.
2. ————, STANTON, T. R., and WARBURTON, C. W. Improved oat varieties for the corn belt. U. S. D. A. Bul. 1343. 1925.
3. LEVINE, M. N., and SMITH, D. C. Comparative reaction of oat varieties in the seedling and maturing stages to physiologic races of *Puccinia graminis avenae*, and the distribution of these races in the United States. Jour. Agr. Res., 55: 713–729. 1937.
4. MURPHY, H. C. Physiologic specialization in *Puccinia coronata avenae*. U. S. D. A. Tech. Bul. 433. 1935.
5. ————. Reaction of the Victoria oat variety to crown rust. Phytopath., 26:396–397. 1936.
6. ———— and LEVINE, M. N. A race of crown rust to which the Victoria oat variety is susceptible. Phytopath., 26:1087–1089. 1936.

7. ———— and STANTON, T. R. Oat varieties highly resistant to crown rust. Jour. Amer. Soc. Agron., 22:573–574. 1930.
8. REED, GEORGE M. Physiologic races of oat smuts. Amer. Jour. Bot., 11:483–492. 1924.
9. STANTON, T. R. Superior germ plasm in oats. U. S. D. A. Yearbook, 1936: 347–414. 1936.
10. ————, GRIFFEE, FRED, and ETHERIDGE, W. C. Registration of varieties and strains of oats. Jour. Amer. Soc. Agron., 18:935–947. 1926.
11. ————, LOVE, H. H., and GAINES, E. F. Registration of varieties and strains of oats. III. Jour. Amer. Soc. Agron., 20:1323–1324. 1928.
12. ———— and MURPHY, H. C. Oat varieties highly resistant to crown rust and their probable agronomic value. Jour. Amer. Soc. Agron., 25: 674–683. 1933.
13. ————, MURPHY, H. C., COFFMAN, F. A., and HUMPHREY, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24:165–167. 1934.

EFFECTS OF VERNALIZATION ON CERTAIN VARIETIES OF OATS[1]

J. W. TAYLOR AND F. A. COFFMAN[2]

IN the southern United States, fall-sown oats are uniformly more successful than are spring-sown oats and winter-killing of suitably adapted varieties is not a common occurrence especially in the Gulf Coastal region. However, winter-killing of oats occurs more frequently as one progresses northward in the United States until finally fall-sown oats usually fail to survive satisfactorily or not at all. Oats of the *Avena byzantina* species, i.e., the red oat varieties, Red Rustproof and Fulghum and their various strains and hybrids, are best adapted in most of the southern half of the United States and they can be grown from both fall and spring seeding.

Numerous field experiments have demonstrated that Fulghum and especially Red Rustproof oats, varieties of *Avena byzantina*, require early spring seeding for satisfactory growth and normal maturity. Stadler (5),[3] in date-of-seeding experiments in Missouri, demonstrated what probably is a difference in the temperature requirements of the Fulghum and Kherson varieties of oats. When seeding was delayed one month, Fulghum suffered a reduction in grain yield of 45%, whereas Kherson, a variety of *A. sativa*, was reduced only 10%. Kherson is classed as a true spring variety, whereas Fulghum may be considered intermediate, i.e., it does not have a complete winter growth habit but requires a period of cool temperatures before normal heading can occur.

The process of satisfying this low temperature requirement either by natural or artificial means is known as vernalization or iarovization, and the economic possibilities of this phenomenon in cereal production have been the subject of some interest and controversy among investigators in recent years. Experiments on artificial vernalization of oats were conducted at the Arlington Experiment Farm, Arlington, Va , from 1933 to 1937, inclusive, and the results are reported herewith.

PREVIOUS WORK

Only a few previous reports on vernalization of oats have been made. Borodin (2) presented results of his vernalization studies of oats in the United States. He obtained definite responses from several winter oat varieties and discussed the practical possibilities of vernalization of oats in America. He was more sanguine of the utility of artificial vernalization than was Martin,[4] who reviewed some of the literature on vernalization and pointed out several limitations to its practical use. Martin stipulated that for vernalization to be practical yields produced from vernalized seed must exceed those resulting from ordinary spring seeding by a sufficient margin to justify the added risk and expense. He further called atten-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication October 3, 1938.

[2]Agronomists.

[3]Figures in parenthesis refer to "Literature Cited", p. 1019.

[4]MARTIN, J. H. Iarovization in field practice. U. S. D. A., B. P. I., Div. Cereal Crops and Dis., Unnum. Pub., 12 pages. 1934. [Mimeographed.]

tion to the physical problems involved in vernalization on a commercial scale. More recently, a comprehensive review of papers on vernalization the world over has been presented in a bulletin published by the Imperial Bureau of Plant Genetics (3). The reader is referred to this publication for a review of literature.

METHOD OF VERNALIZING OATS

The possibility of using vernalization as a method to increase oat yields from spring seeding to a point approximating the yields of fall-sown oats or surpassing the yields for early spring-sown oats has been investigated at Arlington Farm, Arlington, Va., since 1933.

The steps in the vernalization of the oat seed grown in these experiments were as follows:

1. Approximately 4 pounds of seed of each variety were placed in a cotton bag and soaked in tap water at a temperature of 60° to 65° F for 18 to 24 hours.

2. The excess water was drained off and the bags of oats stored without further attention at a temperature of 32° to 34° F for from 28 to 45 days.

3. The seed was then surface-dried and sown in 15-foot rows replicated two or three times in three-row plats. Untreated lots of each variety were sown adjacent to the vernalized seed. In 1936 and 1937 a second treatment was included. In this the seed was soaked in tap water just prior to seeding but was not subjected to chilling. This latter treatment produced approximately the same results as when dry seed was sown and the data are therefore omitted. Approximately the same number of seeds was sown in all rows of the tests.

4. In 1933, the seed was vernalized 36 days and sown April 10; in 1934, vernalized 42 days and sown April 9; in 1935, vernalized 37 days and sown March 29; in 1936, Iogold, Frazier, and Nortex were vernalized 37 days and all others 45 days and all were sown March 30; in 1937, they were vernalized 28 days and sown April 13.

The three characters studied were (a) heading date, (b) yield, and (c) smut infection. The seed was inoculated with mixtures of spores of loose smut (*Ustilago avenae*) and covered smut (*U. levis*). Several different spore mixtures were used, depending upon the variety, and an attempt was made to inoculate each variety with a smut collection to which it was known to be susceptible. Data are presented in Table 1.

EXPERIMENTAL RESULTS

DATE OF HEADING

The period from seeding to heading, the yield per acre, and the percentage of smutted panicles are given in Table 1. The date of heading of the typically spring varieties was not greatly influenced by vernalization (Table 1). Silvermine and Richland, grown only in 1933, showed no influence at all. Iogold headed in 69 days from untreated seed as compared with 71 days for the vernalized seed for the 4-year period 1934–37. This delay in heading probably resulted from reduced stands in plats from vernalized seed as well as to slower growing and less vigorous seedlings as is shown in Fig. 1, A.

The two Fulghum strains averaged 6 days earlier in heading as a result of vernalization in the 4 years. The greatest difference between treated and untreated seed of C. I. 708 occurred in 1936 when the plants from treated seed headed 12 days earlier than those from un-

TABLE 1.—*Number of days from seeding to heading, yield per acre in bushels, and the percentage of smutted panicles for vernalized and untreated oats during the 5-year period, 1933–1937.*

Variety	Treatment	Period from seeding to heading, days						Yield per acre, bu.					Percentage of smutted panicles			
		1933	1934	1935	1936	1379	Av.	1934	1935	1936	1937	Av.	1935	1936	1937	Av.
						Avena sativa										
Iogold	None	—	64	71	70	72	69	52.0	53.0	60.6	22.4	47.0	2.0	1.9	9.8	4.6
	Vernalized	—	64	73	74	72	71	38.2	35.8	27.2	17.8	29.8	Trace	0	0	0
Richland	None	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Vernalized	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Silvermine	None	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Vernalized	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lee (winter)	None	80	—	80	74	80	79	—	59.2	57.4	2.6	39.7	2.1	6.2	17.0	8.4
	Vernalized	63	—	77	71	74	71	—	55.0	42.8	13.4	37.1	Trace	2.1	1.8	1.3
Winter Turf (winter)	None	63	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Vernalized	54	—	—	—	—	—	—	—	—	—	—	—	—	—	—
						Avena byzantina										
Fulghum (C. I. 708)*	None	65	—	70	70	73	70	—	59.0	66.4	21.4	48.9	—	1.8	17.1	9.5
	Vernalized	59	—	68	58	71	64	—	62.4	38.0	27.8	42.7	—	0.3	0.4	0.4
Fulghum (winter)	None	—	75	72	70	76	73	51.2	53.8	54.2	2.6	40.5	1.9	7.0	3.3	4.1
	Vernalized	—	61	70	63	72	67	49.8	57.8	50.2	30.4	47.1	0.4	Trace	0.7	0.4
Frazier	None	—	66	69	68	72	69	65.2	47.0	75.4	16.6	51.1	—	1.5	13.9	7.7
	Vernalized	—	56	67	58	69	63	61.6	72.4	56.8	27.0	54.5	—	0	0.4	0.2
Nortex	None	—	70	73	71	76	73	37.0	41.6	66.6	10.6	39.0	—	—	—	—
	Vernalized	—	60	71	63	72	67	48.4	72.8	43.4	25.2	47.5	—	—	—	—
Average†	None	69	70	73	71	75	72	51.1	52.1	64.0	10.8	44.5	2.0	4.1	12.8	6.3
Average†	Vernalized	59	59	71	63	72	65	53.3	64.1	46.2	24.8	47.1	0.2	0.6	0.8	0.5

*C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
†Not including the true spring varieties Iogold, Richland, and Silvermine.

treated seed. Frazier and Nortex (Fig. 1, B), for the 4-year period, averaged 6 days earlier in heading when grown from vernalized seed. The least difference in date of heading was 2 days and the greatest 10 days.

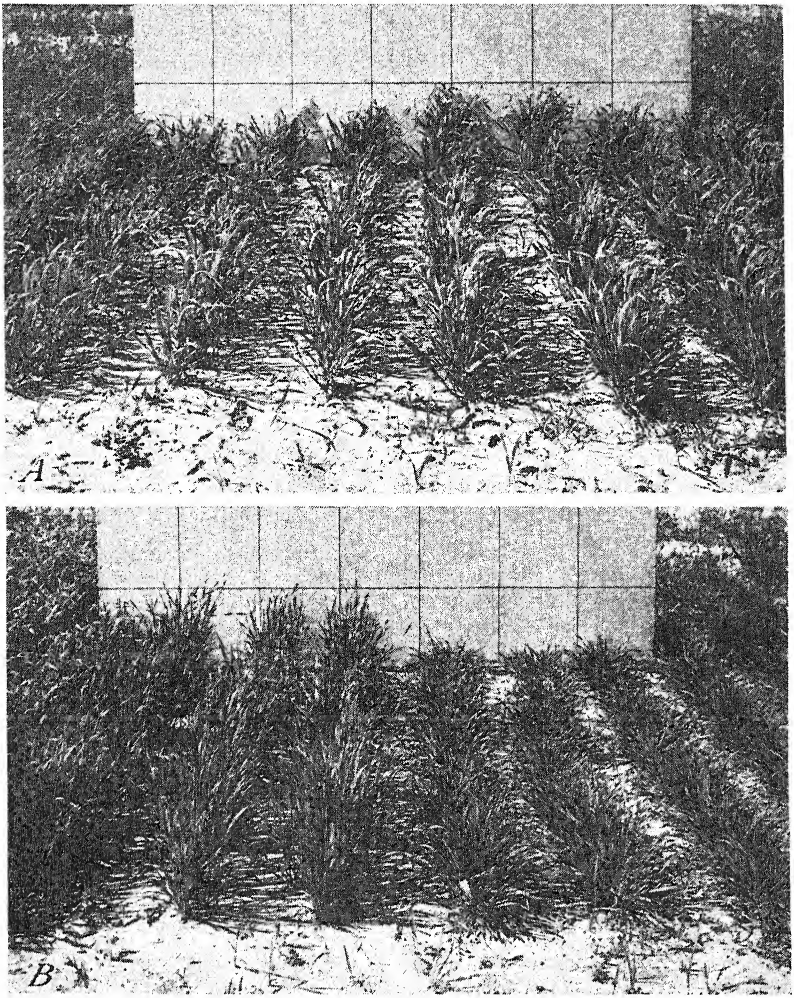

FIG. 1.—*A*, Iogold, a true spring oat variety; vernalized 3 rows at left; check on right. *B*, Nortex, an "intermediate" type variety; vernalized 3 rows at left; check on right.

The time elapsing from seeding to heading for treated seed of Lee averaged 8 days less than for untreated seed. Lee probably requires more time for vernalization than the other varieties.

TABLE 2.—*Species, growth habit, maturity, and vernalization response of oat varieties.*

Variety	C. I. No.	Growth habit	Maturity	Type as determined by vernalization response
		Avena sativa		
Iogold	2329	Spring	Early	Spring
Richland	787	Spring	Early	Spring
Silvermine	659	Spring	Midseason	Spring
Lee	2042	Winter	Late	Winter
Winter Turf	431	Winter	Late	Winter
		Avena byzantina		
Fulghum (winter type sel. 699–2011)	2499	Winter	Midseason	Intermediate
Frazier	2381*	Spring	Early	Intermediate
Fulghum	708*	Spring	Early	Intermediate
Nortex	2382*	Winter	Midseason	Intermediate

*Grown both from spring and fall seeding. Frazier and Fulghum are intermediate in growth habit when fall sown.

In Table 2 the varieties are classified according to their response to vernalization, growth habit, relative maturity, and species for comparison. The classification according to vernalization response is based on the differences in dates of heading of vernalized and unvernalized seed.

INFLUENCE OF VERNALIZATION ON YIELD

The grain yields of Iogold, a spring variety, were reduced by the treatment in all 4 years, averaging 37% less grain than from the untreated check (Table 1). This no doubt was due mainly to poor germination, since the stand in the vernalized rows for the 4 years averaged only 51% of that in the untreated rows. It is probable that vernalization, at least under these conditions, is injurious to the resulting crop unless more important factors exist, such as a low temperature requirement. All varieties averaged at least 20% poorer stand in rows from vernalized seed.

Fulghum (C. I. 708) gave greater yields from the vernalized seed in 2 of the 3 years, but the average for all years was almost 13% less for the vernalized seed.

The vernalized seed of Frazier gave greater yields in 1935 and 1937 and poorer yields in 1934 and 1936 than untreated seed. For the 4 years the increased yield from treatment was but 7%.

Nortex (a strain of Red Rustproof) averaged almost 22% higher in grain yield from the treated seed than from the untreated seed for the 4-year period. Appreciable increases occurred in 1934, 1935, and 1937, while a decrease of 35% occurred in 1936.

Fulghum (C. I. 2499) showed an increase from the treatment in 1935 and 1937, but in 1934 and 1936 there was a slight decrease. For the 4 years there was a gain for the treatment of approximately 16%.

Vernalizing Lee reduced the yield 7%. Decreases were recorded in 2 of the 3 years.

An examination of the data for 1936 and 1937 indicates what may occur as a result of vernalization. In 1936 the seed of certain varieties was treated for 45 days, or 2 weeks longer than was intended, because weather and soil conditions did not permit seeding before March 30. Stands in the vernalized rows were less than 50% that year. Iogold was reduced in yield by 55%, whereas in 1937 the yield of Iogold was reduced only 20% because the treatment was for only 28 days and weather conditions for seeding were more favorable. The seeding date, April 13, was so late that only the vernalized winter varieties made a fair yield.

COMPARISON OF VERNALIZED OATS WITH HIGH-YIELDING SPRING-SOWN AND FALL-SOWN VARIETIES

The yields from the vernalized seed can be compared directly with those of high yielding spring and intermediate type Fulghum oats grown on comparable adjoining land. The spring oat nursery was sown as early as possible. In 1934 and 1936 both the vernalized and spring oat nurseries were sown on the same dates, April 9 and March 30, respectively. The spring oat nursery was sown March 19 or 10 days earlier than the vernalized nursery in 1935, whereas in 1937 the spring oat nursery was sown March 24 or 20 days before the vernalized experiment.

Columbia, a spring oat, averaged 55.4 bushels per acre for the period 1934 to 1937, inclusive. Frazier, grown from vernalized seed, averaged 54.5 bushels for the same years. The yields of Fulghum in the spring oat nursery did not differ materially from those obtained in the vernalized experiment.

The Frazier variety produced the highest average yield from the vernalized seed in the 4-year period. Lee oats, when fall sown, produced over 21% more grain than the vernalized Frazier for the same 4-year period. Even Fulghum (C. I. 708) which was almost entirely winter-killed in 1936 yielded slightly more grain in the 4 years than vernalized Frazier and almost 30% more grain than spring-sown vernalized Fulghum.

EFFECT OF VERNALIZATION ON OCCURRENCE OF SMUT

More smut was observed in the untreated rows of both Lee and Winter Turf in the preliminary vernalization experiment in 1933. The crop of 1934 contained no smut. In 1935, Iogold, Fulghum (C. I. 2499), and Lee again showed much less smut in the crop from treated seed. The seed used in 1936 and 1937 was artifically inoculated with smut before it was vernalized. A sample of the seed of each variety was soaked before sowing to determine the effect of soaking without vernalization on subsequent smut occurrence. An average number of 40.5 smutted panicles per row was found in the soaked seed lots, whereas the dry or untreated seed produced 37.9 smutted panicles per row. This difference is not considered significant. Iogold averaged 4.6% smutted panicles per row (Table 2) as compared with

only 1 smutted panicle in all 3 years in the plants from the vernalized seed. In Fulghum (C. I. 708) there was an average of 9.5% smutted panicles per row from the untreated seed and but 0.4% from that vernalized. Frazier, Fulghum (C. I. 2499), and Lee all showed similar reductions in smut when the seed was vernalized.

Nemlienko (4) found that vernalized or iarovized wheat had only one-third as much stinking smut or bunt (*Tilletia tritici*) as unvernalized wheat.

Bartholomew and Jones (1) found the optimum temperature for infection of oats with *Ustilago avenae* to be 20° C. The minimum temperature for spore germination was 5° C, appreciably above the vernalization temperature (32° to 34° F) used in the present experiments.

The germination and stands of the vernalized oats in the field sowings were reduced as compared to those from the untreated oats. Smut-infected seedlings, if weaker than the normal seedlings, might be eliminated during vernalization or early growth. In 1937, an experiment was conducted in the greenhouse to obtain further information on the effect of the low temperatures on smut occurrence. A lot of Frazier oats was smutted heavily and half of it was soaked for 18 hours in tap water and stored for 3 weeks at 32° to 34° F. The other half was soaked for 18 hours prior to seeding. A seeding of 110 kernels of each of the two lots was made on the same day. More than 100 plants were produced by each lot. The stands were approximately equal, but the untreated seed produced 57.7% smut whereas the vernalized produced 32.1%. Under greenhouse conditions both germination of and smut occurrence in plants from vernalized seed were noticeably higher than under field conditions.

RELATION OF LOW TEMPERATURE REQUIREMENT TO ADAPTATION OF OAT VARIETIES

In Fig. 2 are shown graphically the lines along which seeding of spring oats is begun on the average on February 15, March 15, and April 15 in the eastern and central United States, and the mean temperature isotherms of 40° and 50° F for February, March, and April.

There is a close relationship between the 50° F March isotherm and the northern limit of the zone in which oats of the Red Rustproof type give best results from spring sowing. The Red Rustproof oat usually does not yield satisfactorily when sown north of this line, because it frequently does not reach the heading stage sufficiently early to escape injury from hot weather. Fulghum, on the other hand, matures earlier, permitting it to escape summer heat.

Fulghum oats when spring sown usually do not develop satisfactorily when seeded much north of the area in which spring seeding of oats begins by March 15. In addition, Fulghum oats rarely yield better than oats of the *Avena sativa* type when sown north of the 50° F April isotherm.

In recent years, many farmers in Nebraska and Iowa have followed the practice of seeding Fulghum oats in February or even late in January when weather permitted. Oats sown at these early dates are locally spoken of as winter oats and frequently outyield the varieties

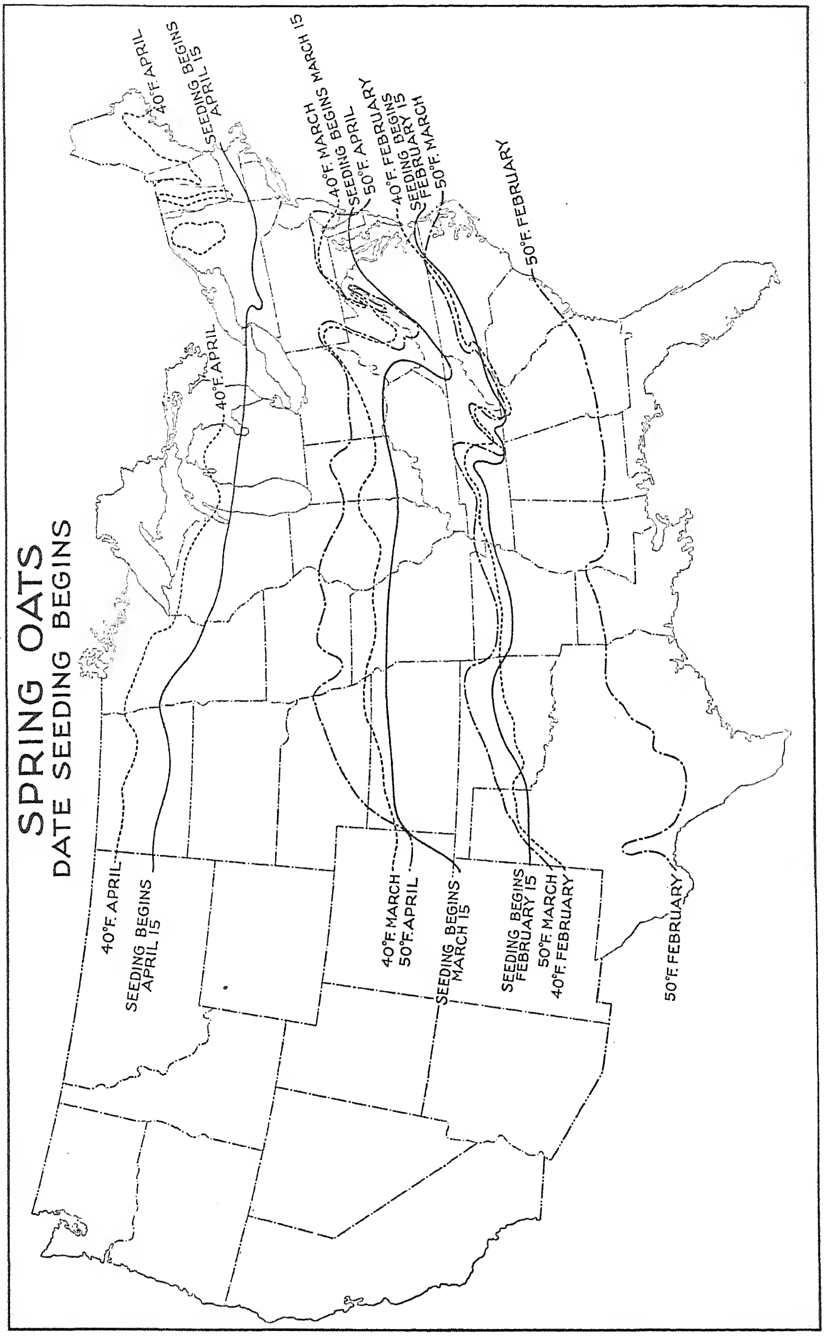

FIG. 2.—Relation of temperature to the time of seeding spring oats in the United States.

sown at the usual seeding date. Doubtless the reason for the favorable yields obtained from such early seedings is that the low temperature requirements of the variety are satisfied which is not the case when sown at the usual seeding date.

This distribution of Red Rustproof and Fulghum, the early seeding dates recommended, and the temperatures at this time seemingly are the result, in part at least, of the low temperature requirements of the varieties. Martin[5] suggested this probable temperature relationship in Fulghum oats in discussing the results presented by Stadler (5). Other than this brief reference, no discussion of the probable low temperature requirement as an explanation for the necessity for early seeding of the red oat has been found. Frazier and Nortex are red oat (*Avena byzantina*) types and both responded to vernalization. Iogold, Silvermine, and Richland varieties of *Avena sativa* showed no low temperature response and these varieties are no doubt less affected by seeding date. This probably explains the big decrease in yield reported by Stadler (5) when he sowed Fulghum a month late as compared with Kherson, a spring variety which has no similar low temperature requirement. Table 3 indicates a probable relationship of cool temperatures following seeding to yield of Fulghum and Kherson oats as reported by Stadler (5) for Columbia, Mo., in 1921, 1923, and 1924. For most favorable results, it is probable that Fulghum and Red Rustproof should be sown during a period when the average

TABLE 3.—*Average mean and minimum temperatures during the 15- and 21-day periods following seeding oats at Columbia, Mo., together with yields obtained.**

Seeding date of oats	Average temperature in °F following seeding: 21 days, Mean	21 days, Minimum	15 days, Mean	15 days, Minimum	Yield per acre, bu.: Fulghum	Kherson
			1921			
March 17	54.4°	43.7°	51.5°	41.3°	55.3	37.2
March 31	53.9°	43.3°	55.0°	44.9°	42.5	37.0
April 14	54.5°	44.5°	56.5°	46.2°	31.4	30.0
April 28†	57.0°	48.0°	55.9°	47.3°	6.3	13.4
			1923			
March 5	38.4°	27.8°	36.2°	26.8°	42.1	35.7
March 27	45.7°	34.4°	43.9°	31.7°	34.0	29.6
April 12	57.7°	47.1°	55.1°	44.3°	17.8	30.3
			1924			
March 22	48.1°	38.0°	44.8°	35.7°	60.6	48.2
April 5	59.0°	47.1°	58.7°	46.7°	53.7	48.9
April 12	58.9°	47.5°	60.3°	48.7°	38.2	40.5
April 19	58.4°	47.8°	58.0°	46.7°	37.8	42.9
April 26	56.3°	46.0°	57.1°	47.3°	39.2	39.2

*Yields quoted from Stadler (5). Temperature records for Columbia, Mo., are from Climatological Data of the U. S. Dept. of Agriculture Weather Bureau.

†It seems probable that the very low yields obtained from the seedings of April 28, 1921, were at least partly due to heat injury before the plants ripened.

[5]See footnote 4.

minimum temperature is about 40° to 45° F and that they should be in the ground possibly a month at least before the mean temperature exceeds 55° F. These varieties are both spring and fall sown in the United States and they possess a low temperature requirement which must be satisfied for best yields.

SUMMARY

Six oat varieties were vernalized in each of 4 years. Two were winter varieties, three were intermediate in growth habit, and one was a spring variety. Winter and intermediate varieties require a period of cool temperatures for normal growth and development. It is probable that the red oat varieties, Fulghum and Red Rustproof, should be planted in the spring when the average minimum temperature is about 40° to 45° F.

The vernalization of oat seed hastened the heading date 2 to 10 days in the varieties with a low temperature requirement. An average shortening of the period from seeding to heading of 6 days, due to vernalization, was obtained in these varieties during the 4 years. Spring oats showed no hastening of heading, the Iogold variety having been retarded by vernalization in certain years.

Frazier, Nortex, and Fulghum (C. I. 2499), on the average, yielded higher from the vernalized seed than from untreated seed. The greatest increase occurred in Nortex in which the average yield was over 20% higher. Lee and Fulghum (C. I. 708), as well as the spring variety Iogold, showed decreased yields from vernalization. The 4-year average yield from untreated seed of the spring variety, Iogold, was the same as the average of the five winter and intermediate types after vernalization. Spring oats sown early outyielded all of the vernalized oats and fall-sown oats yielded about 20% more grain than the highest yielding vernalized variety.

Vernalization greatly reduced the occurrence of oat smut. Iogold, in the 3 years that smut occurred, had an average of 4.6% smutted panicles per row as compared with but one smutted panicle in the vernalized rows in all 3 years.

LITERATURE CITED

1. BARTHOLOMEW, LUCILLE K., and JONES, EDITH SEYMOUR. Relation of certain soil factors to the infection of oats by loose smut. Jour. Agr. Res., 24:569–575. 1923.
2. BORODIN, DMITRY N. Yarovization formulas for winter oats. New York. 1934.
3. IMPERIAL BUREAUX OF PLANT GENETICS. Vernalization and phasic development of plants. Bulletin No. 17, Imp. Bur. Plant Gen.: Herbage Plants and Occasional Publication of the Imperial Bureau of Plant Genetics, for Crops other than Herbage. Aberystwyth and Cambridge: Imp. Bur. Plant Gen. 1935.
4. NEMLIENKO, F. [On the problem of control of hard smut in connection with iarovization of wheat.] All-Ukrainian Acad. Agr. Sci. (Odessa), Ukr. Inst. Plant Breeding Bul. Iaroviz., 2/3:81–86. 1932.
5. STADLER, L. J. Fulghum oats for Missouri. Mo. Agr. Exp. Sta. Bul. 229. 1925.

PROBLEMS IN EVALUATING PASTURES IN RELATION TO OTHER CROPS[1]

H. L. AHLGREN, G. BOHSTEDT, AND O. S. AAMODT[2]

STUDIES of pasture improvement through fertilization and management are comparatively new. Since 1920 a considerable body of data relative to the effect of fertilization and management on the yield, chemical composition, and survival of various pasture crops has been assembled in the United States and elsewhere. Valuable as this early work has been, there is an urgent and ever-growing need for additional information which would permit of an accurate evaluation of pasture crops in relation to each other and to other crops grown as feed for livestock. In general, the pasture agronomist is well fortified with facts and figures relative to increases in production of forage which may be obtained from a well-planned fertilization and management program. However, he is often at a loss to know how best to sell his ideas to those who should be vitally concerned because he cannot interpret his results in terms of relative dollars and cents values. This is due primarily to the scarcity of facts and figures for comparing the relative value of various pasture crops and of pasture crops with other harvested feed crops. Consequently, his work has not found as wide a reception among farmers as the present condition of millions of acres of pasture land would appear to warrant.

At present the number of acres of various pasture crops found on an average farm is determined largely by topography, climate, soil type, and type of farming. In general, the acreage devoted to pasture is not based on the value of pasture in relation to other crops grown on the farm. Agronomists have gone ahead on the assumption that a certain amount of land in pasture makes for greater efficiency in land use. It is the purpose of this paper to present the problems associated with, and call attention to, the need for evolving a technic which can be used in evaluating various types of pasture crops in relation to themselves and to other crops which are grown as feed for livestock. It is only through studies of this type that a proper valuation can be placed on crops which are grown for and harvested by livestock.

PRODUCTION RECORDS NEEDED

On a well-managed dairy farm accurate production records are kept for each of the producing animals. In this way it has been possible to remove unprofitable, inefficient, low producers from the herd. It would appear that the same principle could be made use of in evaluating such pasture crops as Kentucky bluegrass, timothy, alfalfa, sweet clover, sudan grass, rye, oats, and others in relation to each

[1]Paper read as part of a symposium on "Comparative Nutritive Value of Crops" at the summer meetings of the A.A.A.S. held at Ottawa, Canada, June, 1938. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication October 5, 1938.

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other and to other harvested feed crops. No doubt there are many situations where crops now used would be replaced were their actual performance values known. At present there are insufficient data with which to compare the nutritive value of various pasture crops with each other and with other feed crops. Such limited data as are available are not in agreement. This would be expected in view of the diversity of soil, topography, climatic conditions, and the species available for grazing which exist in the United States. The limited work that has been done serves to emphasize the need for further extensive investigation in all regions where livestock farming is of major importance.

White (28),[3] working in Pennsylvania, has reported that a 4-year, 4-acre rotation of corn, wheat, oats, and hay produced 8,407 pounds of total digestible nutrients as compared with 8,535 pounds of total digestible nutrients from a 4-acre pasture made up largely of Kentucky bluegrass during the same period. He concludes that "the economic importance of pasture feeding as compared with a system of grain rotation seems to justify the use of land for highly productive pastures similar to that now used for cultivated crops." On the other hand, it is extremely doubtful if the average run of non-rotational pastures are as productive as other crop lands. Generally they have been relegated to the poorest land on the farm. Such fertilizers as have been used have been applied to other crops. In a survey conducted in Wisconsin (15) and covering a 14-year period (1914–1927, inclusive), it was found that the lowest acre production of total digestible nutrients was obtained from permanent pastures. Detailed results of this survey appear in Table 1.

TABLE 1.—*Comparison of the amount of digestible feed nutrients produced per acre by different crops, 14-year average.*

Crop	Total digestible nutrients produced per acre, lbs.
Alfalfa	2,683
Alfalfa (limed)	3,096
Clover	1,838
Timothy	1,552
Corn silage	2,905
Corn	1,939
Barley	1,250
Oats	867
Kentucky bluegrass pasture	846

There is little agreement between the Wisconsin and Pennsylvania figures. There is need for further clarification of the problem with greater consideration directed toward the relative value of various species of crops used for pasture. There is reason to believe that the Wisconsin figures represent the situation more nearly with respect to pastures in general than those obtained in Pennsylvania.

Among the crops listed in Table 1 alfalfa is undoubtedly favored by being grown on the best land on the farm. Likewise, it is generally

[3]Figures in parenthesis refer to "Literature Cited", p. 1028.

true that no attempt has been made to maintain pastures at the same level of fertility as that common for the other harvested feed crops. For this reason the data presented in Table 1 may be somewhat misleading. Under conditions as they now exist any attempt to evaluate permanent pastures in relation to other pasture crops and to crops harvested to be fed to livestock would obviously be unfair. It is to be emphasized that a correct and satisfactory evaluation of pasture crops can be obtained only under conditions where soil fertility conditions are comparable.

COST OF PRODUCTION RECORDS NEEDED

There is very little direct evidence in the literature relative to the cost of producing livestock and livestock products from pasture crops and from harvested crops to be fed to livestock. No attempt has been made to evaluate various types of pasture. It would appear just as desirable to know how much it will cost to produce a crop as to know how much the crop will produce. Obviously the cost of producing various pasture crops as compared to other crops will not be constant for all regions. It will vary from region to region depending upon economic conditions, length of growing period, rainfall, temperature, and soil conditions prevailing in that region. In general it would appear that the more favorable the environment as far as any given species is concerned, the lower the cost of production.

Misner (16) in a detailed study conducted in New York State found that the total cost of pasture and feed used to supplement the pasture was \$.097 per cow per day and the cost of winter feed was \$.38 per cow per day. The returns from milk during the period the study was made averaged \$.34 per cow per day. Figures released by the U. S. Dept. of Agriculture (29) from studies relative to the cost of production of 100 pounds of total digestible nutrients from various crops grown in 16 states are shown in Table 2.

TABLE 2.—*Cost of producing 100 pounds of total digestible nutrients from various crops.*

Crop	Total digestible nutrients produced by crop	Cost of producing 100 lbs. of total digestible nutrients
Oats	932	2.02
Wheat	1,146	1.88
Barley	1,217	1.70
Corn silage	2,320	1.54
Corn grain	1,778	1.38
Timothy hay	1,257	1.21
Clover and timothy hay	1,347	1.15
Soybeans	1,725	1.06
Red clover hay	1,622	0.97
Alfalfa hay	2,522	0.83
Pasture	—	0.64

Lush (14) in cost of production studies in Louisiana found that butterfat could be produced for 13 cents per pound less on pasture than in winter manger feeding.

The comparatively high cost of barn feeding in relation to pasture feeding has been questioned by some. In most studies which have been made to date all costs of production, including an estimated hourly wage for labor, have been assessed against harvested feed crops. In some cases these costs have been included in making comparisons between the economy of barn and pasture feeding. During the period the cattle are on pasture the farmer devotes practically all of his time toward the care of crops to be fed to his livestock in the winter months. During the winter months the livestock producer has no major interest beyond the care of his livestock. Nevertheless, an additional labor charge incurred through handling and feeding the harvested crops is sometimes included in the cost of production figures. It would appear questionable if these labor costs charged against harvested feed crops are entirely justifiable. The services of the farmer for the care and management of his farm are available at all times. From a purely practical point of view he is interested in a balanced labor distribution program. He has found this possible only when a variety of crops are grown and a diversified type of agriculture is practiced. These facts should warrant due consideration in any studies where comparative costs are being determined.

The limited data which are available relative to comparative costs of milk production in barn feeding and from pasture would appear to indicate conclusively that pastures offer the livestock producer his cheapest and most economical source of feed. Whether the results which have been reported will obtain under all conditions and for all types of pasture crops prevalent in the United States is problematical and can be determined only by further experimentation. The need for clarification and the desirability of developing an accurate, standardized basis for comparing relative feed costs is apparent. Undoubtedly, work of this nature would serve to stimulate a more general interest in pasture improvement.

METHODOLOGY USED IN EVALUATING PASTURES

The lack of information on the value of various pasture crops from the standpoint of cost of production, nutritive value, and total production is due in no small part to the lack of a satisfactory technic for arriving at a proper evaluation. There are few published data giving quantitative returns in terms of livestock gains and livestock products from various methods of fertilizing and managing pastures or from various species of pasture crops. To date chemical analysis and "lawn mower clippings" have been used as an indirect method of procedure in most cases for evaluating pasture crops. Results obtained by these procedures may not necessarily be the same as those obtained under grazing conditions.

The results of pasture investigations which have been undertaken in the United States would be of considerably more value if the technic used in the evaluation were more uniform. Schuster (25), in a survey of the literature, has pointed out that there are 13 methods of measurement used in determining the productivity of pastures in the eastern United States. The methods listed include profit, hay

weights, clippings, cattle weights, sheep weights, photographs, surveys, carrying capacity, milk flow, plant population, chemical analysis, palatability, and duration of grasses.

The true carrying capacity of any pasture is determined by the amount of feed produced and utilized rather than grazing days obtained or number of livestock units carried. It would appear to the writers that a measure of the efficiency of any pasture can be determined only in terms of livestock and livestock products which are ultimately produced. Maintenance, production, gain or loss in live weight, and amount of supplementary feed required must all be considered in evaluating various types of pastures in terms of each other or in relation to other crops. Calculations of yield of pasture in terms of total digestible nutrients or net energy and digestible protein appear to be the only available procedures which consider these factors. A similar procedure has been adopted in the Scandinavian countries where the system of feed equivalents has been used with reasonable success in measuring the relative values of various feeds.

In general, the value of various feeds in terms of total digestible nutrients supplied has been determined from feeding experiments. Feeding standards for ruminants which assume the use of both harvested roughages and concentrates have been worked out and are generally available. However, there is little information relative to the nutritive value of those forage crops which are grazed in the more immature growth stages. Facts concerning the relative value of these feeds can be determined only through feeding experiments. Lack of appreciation of the need for data of this type, cost, newness of work, and other difficulties of obtaining quantitative results have limited the investigational work.

The advisability and value of feeding experiments to determine the nutritive value of immature pasture forage crops has been questioned by some workers because it has been argued that the climate of the United States is not generally conducive to a uniform growth of forage throughout the growing period. For this reason it has been thought difficult, if not impossible, to graze in such a manner as to maintain approximately the same amount of forage in comparable growth stages at all times. This lack of uniformity of growth has led some to question the possibility of conducting feeding experiments which would be of any scientific value. During the past few years the agronomist has unconsciously aided in making uniform feeding experiments possible through improved pasture technic. It is now generally recognized that no one crop is capable of providing an abundance of highly nutritious forage throughout the growing period. The single-crop pasture plan has been replaced by a plan which calls for a succession of crops each of which is grazed intensively during its period of most rapid growth. By a scheme of rotation the agronomist has been better able to manage the various pasture crops in such a way as to utilize the forage at such times as it is most palatable and nutritious. Under this system of management it should not be difficult to maintain forage in any stage of growth desired. In the north central and northeastern portions of the United States crops such as sudan grass, rye, oats, alfalfa, and sweet clover have been used to

supplement Kentucky bluegrass. There is need for an accurate evaluation of these crops in relation to each other, to Kentucky bluegrass, and to other crops grown as feed for livestock. Their use makes possible a longer pasture season and eliminates the necessity of grazing Kentucky bluegrass in such a manner as to build up a reserve of surplus forage during favorable growth periods to provide feed of unquestionably inferior quality during unfavorable growth periods.

So far it has been shown that cultivated crops and land devoted to these crops have received major attention and consideration from farmers and research workers alike. The use of cultivated crops has been limited to the best land on the farm which is natural in view of greater initial costs involved and the higher more immediate cash returns which are often obtainable. Barnyard manure and commercial fertilizers when used are usually applied to cultivated crop land. Likewise, improved soil practices, tillage operations, and weed control activities have generally been confined to soil other than that on which pasture crops are grown.

Where evaluation studies relative to various pasture crops and harvested feed crops are to be made, the studies must be conducted under conditions where improved pastures and pasture systems as well as improved cultivated crops and proper rotations are being compared. There can be no other justifiable basis for an accurate evaluation. Such evaluations would aid materially in demonstrating that a planned pasture improvement program based on scientific facts is practical, feasible, and economical. It would also be in accordance with soil conservation and erosion control practices where pasture improvement has been accepted as fundamental.

PRESENT FEEDING STANDARDS NOT ENTIRELY SATISFACTORY

It is to be emphasized that no method of measuring the nutritive value of feeding stuffs yet devised is entirely satisfactory. In the United States the "total digestible nutrients" method has been most widely used in comparing one feed with another. This procedure is satisfactory only when feeds being fed for productive purposes have approximately the same fiber content. In view of this fact various attempts have been made to place various feeds on a common basis with respect to their productive values.

Kellner (12) in Germany developed his "starch values", Armsby (1) and Fraps (6) in the United States, the net energy and productive values, respectively. By using net energy values it is possible to compare concentrates of low fiber content with roughages of high fiber content. However, few relative data are available regarding net energy values of feeding stuffs. Furthermore, no system of feed evaluation yet devised adequately considers palatability and quality of proteins, minerals, and vitamins.

Crampton (3) in work with reed canary grass has shown that proteins present in this forage may be of inferior quality. Orr (23) in a comprehensive review of the world literature has demonstrated the necessity of balanced mineral intakes in the health and well being of livestock. Steenbock, et al. (27) and Russell (24) found that clover

hay which had been exposed to sunlight and rain was less valuable as a source of vitamin A than hay cured quickly and still retaining a good green color. Douglas, Tobiska and Vail (4) found that alfalfa hay, cut early, contained more vitamin A and G than hay cut at later growth stages. Hunt and Krauss (11) in a study with various pasture grasses have shown that vitamins A and G decreased as plants approached maturity. Barnes and Hume (2) have shown that milk from cows on pasture contained more vitamin C than milk from cows on winter feed. In 1923, Golding (8) reported that milk from winter feeding might contain as little as one-tenth the vitamin A of milk from cows fed on pasture. Hunt, Record, and Bethke (10) have shown that the vitamin B and G content of alfalfa, clover, and timothy decreased as the plant approached maturity.

Certainly any method or methods of feed evaluation, however accurate otherwise, which does not consider the facts discussed above, is faulty. For the present at least it seems highly desirable to determine as quickly as possible by the technics available the *relative values* of various pasture crops in relation to each other and to other harvested feed crops.

INDIRECT METHOD OF DETERMINING RELATIVE VALUES OF PASTURE FEEDS

From feeding standards and through many years of experimentation there is available a fairly accurate body of data relative to the total digestible nutrient requirements for maintenance and milk production of dairy cows. By computing the requirements for maintenance, milk production, and gain in live weight and by deducting nutrients obtained from supplementary feeds, the amount of nutrients supplied by various pasture crops can be calculated. If accurate yields of forage produced are taken, the digestibility of the forage can be calculated with reasonable accuracy.

On the basis of feeding standards prepared by Haecker (9), Morrison (18), and Forbes, et al. (5), Knott, Hodgson, and Ellington (13) have determined the total digestible nutrients supplied by a number of Washington pastures. On the basis of their evaluations they found that an acre of pasture on which rotational grazing was practiced produced an average of 5,986 pounds of total digestible nutrients annually during the period 1931–33, inclusive. A continuously grazed pasture produced an average of 5,499 pounds of total digestible nutrients annually during the same period, whereas reed canary grass produced 5,254 pounds of digestible nutrients annually. The average acre yield of digestible nutrients from wheat pasture was 1,875 pounds. A similar procedure has been used by Sprague (26) in evaluating pastures of New Jersey. This system is also being used at Wisconsin in an attempt to evaluate various fertilization and management procedures in terms of digestible nutrients supplied from pastures.

Standards similar to those used in computing the nutrient requirements of milk-producing dairy cattle are also available for growing dairy cattle, beef, cattle, horses, and sheep. The method may be open

to criticism because it is indirect; however, it would appear to be reasonably accurate for determining *relative values* of various pasture forages. It should prove highly useful and valuable until such a time as more exhaustive studies have been made on such questions as digestion coefficients and net energy or productive values of the pasture forages; also on maintenance requirement of livestock on pasture. Obviously, pasture research can be broken down into a great many separate steps, or simple variant comparisons, each of which is a problem in itself.

DIRECT METHOD OF DETERMINING RELATIVE VALUES OF PASTURE FEEDS

An exact knowledge of the feeding value of various pasture forages would be extremely valuable. Unfortunately there is very little information in the literature relative to the feeding value of crops grazed at immature growth stages. Newlander (19) determined the coefficient of digestion of oat hay, sudan grass, and millet, all of which were harvested and fed at immature growth stages. Each of the materials was fed as the sole ration since chemical analyses showed them to be fairly well balanced in nutrients. The digestion coefficients of the dry matter of oat hay, sudan grass, and millet were found to be 70.57, 65.25 and 67.96, respectively. In another feeding experiment with sudan grass, Newlander (20) found this forage to contain 58.86% total digestible nutrients on the basis of 86.4% dry matter. Mineral balances obtained in this trial showed losses of calcium and a gain of phosphorus, indicating that dried young sudan grass fed as the sole feed to dairy cows may be deficient in calcium. In further work Newlander and Jones (22) found dried young grass, mostly Kentucky bluegrass, fed as the sole ration to dairy cows to contain 64.37% total digestible nutrients on the basis of 90.17% dry matter. Newlander (21) also substituted artificially dried young grass for hay in a ration and secured increased milk yields. Garrigus and Rusk (7) found young reed canary grass to contain 61.39% total digestible nutrients, whereas brome grass which was practically mature contained 51.79% total digestible nutrients.

As far as the United States is concerned, data relative to the digestibility of various pasture crops is admittedly fragmentary. For the present at least, pasture crop evaluation on this basis is not possible.

According to the best information available, reliable feed values can be determined with any class of livestock by means of feeding experiments which can be conducted at relatively low costs. To be reliable, Morrison (17) suggests that such feeding experiments conform to certain essential facts, as follows:

1. There must be available as a standard for comparison a suitable common feed, the feeding value, or more specifically, the net energy value of which has been definitely established. Dent corn grain would appear to be the best standard for the United States as a whole.

2. The experiment must be arranged in such a way as to determine definitely the amount of feed to be tested which is required to produce the same amount of product as is produced by a definite amount of corn grain of standard composition.
3. All feeds should be carefully analyzed so that a record of the exact composition can be obtained.
4. The check lot which receives corn and the lot which receives the experimental feed must both consume the same amount of all other feeds.
5. The production of the two lots should be equalized as much as possible by increasing or decreasing the amount of experimental feed.
6. The check lot must be fed a sufficient amount of corn and the other feeds that are needed to provide a good and complete ration so that the animals will produce at a satisfactory rate.
7. The animals in both lots must be weighed at periods no longer than 2 weeks. After each weighing the amount of experimental feed must be increased or decreased, if necessary, to equalize the production or gains in weight of the animals in the two lots.
8. At the conclusion of an experiment conducted according to this procedure it will have been determined just how much of the experimental feed has been required to replace each 100 pounds of corn grain that has been consumed by the check lot. From this fact the nutritive value of the experimental feed can be computed.

Perhaps an experimental procedure such as the above can be adapted for comparing pastures among themselves, or for comparing pastures with harvested feeds, primarily roughages. While the harvested feeds could be of a definite quality from the beginning to the end of such an experiment, the pasture might for obvious reasons need to be a rotation or succession of forage crops.

CONCLUSION

It has not been the purpose of this paper to arrive at any definite conclusions relative to the evaluation of various pasture crops. Rather it has been the object to point out the problems involved in such a procedure and the need for, and desirability of, developing a satisfactory standardized technic for evaluating various types of pasture crops. It is evident from a survey of the literature and our own observations, that the type of data needed is not sufficiently complete for general application in the United States. It is the opinion of the authors that a proper evaluation of the producing ability, relative cost, and feeding value of various pasture crops will serve directly in making for a greater efficiency in the use of pasture crops and increased interest in pasture improvement generally.

LITERATURE CITED

1. Armsby, H. P. The Nutrition of Farm Animals. New York. 1917.
2. Barnes, R. E., and Hume, E. M. Relative antiscorbutic value of fresh, dried, and heated cows milk. Biochem. Jour., 13:306–328. 1919.
3. Crampton, E. W. Pasture studies. IV. Nutritive value of pasture herbage: quality of protein. Emp. Jour. Exp. Agr., 2:337–348. 1934.

4. DOUGLAS, E., TOBISKA, J. W., and VAIL, C. E. Studies on changes in vitamin content of alfalfa hay. Colo. Agr. Exp. Sta. Tech. Bul. 4. 1933.
5. FORBES, E. B., FRIES, J., BRAMAN, W. W., and KRISS, M. The relative utilization of feed energy for maintenance, body increase, and milk production of cattle. Jour. Agr. Res., 33:483–492. 1926.
6. FRAPS, G. S. The production coefficients of feeds. Tex. Agr. Exp. Sta. Bul. 185. 1916.
7. GARRIGUS, W. P., and RUSK, H. P. The consumption of reed canary and brome grasses by grazing steers. Proc. Amer. Soc. Ann. Prod., 75–82. 1935.
8. GOLDING, J. Variation of the vitamin A content of cow's milk under different conditions of feeding. Proc. World's Dairy Congress, 1:164–169. 1923.
9. HAECKER, T. L. Investigations in beef production. Minn. Agr. Exp. Sta. Bul. 193. 1920.
10. HUNT, C. H., RECORD, P. R., and BETHKE, R. M. The influence of stage of maturity on the chemical composition and vitamin B (B_1) and G content of hays and pasture grasses. Ohio Agr. Exp. Sta. Bul. 576. 1936.
11. ———— and KRAUSS, W. E. The influence of the ration of the cow upon the vitamin B and vitamin G content of milk. Jour. Biol. Chem., 92:631–638. 1931.
12. KELLNER, O. Ernähr. landw. Nutztiere. 1907.
13. KNOTT, J. C., HODGSON, R. E., and ELLINGTON, E. V. Methods of measuring pasture yields with dairy cattle. Wash. Agr. Exp. Sta. Bul. 295. 1935.
14. LUSH, R. H. Pasture production and management. La. Agr. Exp. Sta. Circ. 15. 1936.
15. MERRIAM, L. J. Comparison of the amount of digestible feed nutrients produced per acre by different crops. Unpublished data.
16. MISNER, E. G. Income from crop and pasture land. Jour. Amer. Soc. Agron., 21:594–603. 1929.
17. MORRISON, F. B. Determining net energy values by means of feeding experiments. Proc. Amer. Soc. Ann. Prod., 12–20. 1937.
18. ————. Feeds and Feeding. Ithaca, N. Y.: Morrison Publ. Co. Ed. 20. 1936.
19. NEWLANDER, J. A. The digestibility of artifically dried roughages. Vt. Agr. Exp. Sta. Bul. 400. 1935.
20. ————. The digestibility of artifically dried sudan grass. Vt. Agr. Exp. Sta. Bul. 386. 1935.
21. ————. The feeding value of artifically dried young grass. Vt. Agr. Exp. Sta. Bul. 350. 1933.
22. ———— and JONES, C. H. The digestibility of artifically dried grass. Vt. Agr. Exp. Sta. Bul. 348. 1932.
23. ORR, J. B. Minerals in pastures in relation to animal nutrition. London. 1927.
24. RUSSELL, W. C. The effect of the curing process upon the vitamin A and D content of alfalfa. Jour. Biol. Chem., 85:289–297. 1929.
25. SCHUSTER, G. L. Methods of research in pasture investigations. Jour. Amer. Soc. Agron., 21:666–673. 1929.
26. SPRAGUE, H. B. A study of permanent pastures of New Jersey. N. J. Agr. Exp. Sta. Circ. 141. 1928.
27. STEENBOCK, H., HART, E. B., ELVEHJEM, C. A., and KLETZIEN, S. W. F. Dietary factors influencing calcium assimilation. The antirachitic properties of hays as related to climatic conditions with some observations on the effect of irradiation with ultra violet light. Jour. Biol. Chem., 66:425–440. 1925.
28. WHITE, J. W. Comparative returns in feed units from crop rotation and pasture. Jour. Amer. Soc. Agron., 21:589–593. 1929.
29. WOODWARD, T. E., and SHEPHERD, J. B. U. S. D. A. Clip Sheet 949. 1936.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, VIII[1]

T. R. STANTON[2]

THE seventh report on the registration of improved oat varieties was published in December 1935 (4).[3] No varieties were registered in 1936 and 1937. The varieties submitted and approved for registration in 1938 are as follows:

Group and Varietal Name	Reg. No.
Early Red:	
Fulton	84
Early yellow:	
Carleton	85
Midseason white:	
Bannock	86

Information on the origin, description, performance, and potential value of these new varieties on which approval for registration is based is summarized in the following paragraphs.

FULTON, REG. NO. 84

Fulton (Kans. No. 6138, C. I. 3327)[4] was originated from a cross between Fulghum and Markton oats made at the Aberdeen Substation, Aberdeen, Idaho, in 1926 by G. A. Wiebe, with the idea of introducing the smut resistance of Markton into the Fulghum type.

The F_1 plants were grown in the greenhouse at the Arlington Experiment Farm, Arlington, Va., in the winter of 1926–27. An F_2 plant population was grown at Aberdeen in 1927 from which panicle selections were made by F. A. Coffman. Fifty of these selections were grown in 1928 by John H. Parker in the oat breeding nursery maintained cooperatively at Manhattan, Kans., by the Kansas Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

The most promising smut-resistant lines were selected through the F_3 to F_5 generations. In 1931 a selected progeny descended from the F_3 panicle row 39 was given selection No. 303635 and sown in triplicated rod rows. After nursery yield tests from 1931 to 1933, seed of this strain was turned over to H. H. Laude, of the Agronomy Department, Agricultural Experiment Station, Manhattan, Kans., for testing in plat experiments in 1934, at which time Kansas accession No. 6138 was assigned to it.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 29, 1938.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1938 Committee on Varietal Standardization and Registration, charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 1036.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

Information on pathologic and agronomic characters forwarded by Dr. Parker, with the application for the registration of Fulton, is summarized in the following paragraph:

For 1931 to 1938, an average of 0.5 and 25.0% of the panicles in Fulton and Kanota, respectively, were infected when the seed was dusted with a composite of Kansas smuts. Fulton has a spreading panicle and a light red kernel that resembles white oats more than Kanota, but it ordinarily will be graded as red oats. Fulton grows from 2 to 3 inches taller, heads from 4 to 6 days earlier, and sometimes ripens from 1 to 3 days earlier than Kanota. The test weight of Fulton is equal or slightly superior to that of Kanota, and like both parents, it is very susceptible to crown and stem rusts. Fulton has a relatively weak straw. Fulton, if planted early, is subject to damage by late spring frosts; however, if planting is delayed, Fulton will usually outyield Kanota.

Briefly then, the superior characters of Fulton are resistance to smut, earliness, high yield, and quality. It will be distributed to farmers of Kansas in the spring of 1939.

Fulton has been tested for yield in nursery rows and field plats at Manhattan, in field plats in regional experimental fields, and in cooperative varietal tests on farms in Kansas. In addition, Fulton has been grown at experiment stations in different States in coordinated yield-test nurseries maintained cooperatively by these states and by the U. S. Dept. of Agriculture. Yield data from these various tests are presented in Tables 1, 2, and 3.

TABLE 1.—*Yield of Fulton and Kanota oats grown in various experiments in Kansas.*

Variety	Acre yield, bushels								
	1931	1932	1933	1934	1935	1936	1937	1938	Av.
Replicated Rod Rows, Manhattan (J. H. Parker)									
Fulton	77.2*	88.9	45.9	21.6	60.3	54.1	60.5	47.0	56.9
Kanota	62.5*	72.3	33.8	12.1	60.5	52.7	60.3	51.7	50.7
Three Distributed 1/40th-acre Plats, Manhattan (H. H. Laude)									
Fulton	—	—	—	23.4†	79.7	51.9	51.4	48.8	51.0
Kanota	—	—	—	21.1†	79.5	58.0	49.5	53.9	52.4
Cooperative Experimental Tests on Farms (A. L. Clapp)‡									
Fulton	—	—	—	—	—	—	37.7	38.5	38.1§
Kanota	—	—	—	—	—	—	36.0	38.3	37.2§

*Three distributed single rod rows in 1931; other years, five distributed plats of three rod rows each.
†One plat only.
‡Five tests each year.
§Average of ten tests.

CARLETON, REG. NO. 85

Carleton (C. I. 2378) was originated from a cross between Sixty-Day and Markton oats made at the Arlington Farm by T. R. Stanton in 1919, at which time the second parent was an unnamed selection (6). The cross was made at the suggestion of D. E. Stephens to

TABLE 2.—*Yield of Fulton and Kanota oats grown in plats on regional experimental fields in Kansas, 1936–38.*

Variety	Region	Location of field	Seeding	Acre yield, bushels						
				1936	1937	1938	Averages			
Fulton	S. E. Kansas	Moran	Early	51.8	57.7	43.2*	50.9	49.2	51.9	56.4
			Late	—	56.3	37.2	46.8			
		Columbus		—	83.6	—	—	83.6		
		Thayer	Early	—	—	53.5	53.5	42.7		
			Late	—	—	31.8	31.8			
	N. E. Kansas	McLouth	Early	56.7	68.0	68.7	64.5	63.6	63.6	
			Late	65.4	59.0	—	62.2			
Kanota	S. E. Kansas	Moran	Early	51.3	52.7	51.3	51.8	45.8	44.8	53.7
			Late	—	47.7	26.1	36.9			
		Columbus		—	70.0	—	—	70.0		
		Thayer	Early	—	—	52.2	52.2	29.7		
			Late	—	—	7.1	7.1			
	N. E. Kansas	McLouth	Early	64.8	70.6	59.3	64.9	68.0	68.0	
			Late	65.5	79.9	—	72.7			

*Injured by early freeze.

develop an oat that would ripen between Sixty-Day and Swedish Select.

In 1921, seed from the F_1 plants grown at Arlington Farm was sown by D. E. Stephens at Moro, Oreg., where it was grown and selected in the F_2 to F_5 generations. In 1925, B. B. Bayles, then at the Sherman Branch Experiment Station at Moro, smutted the seed from 204 selections. Seventy of the F_6 lines were free from smut and 93 showed an infection of 95% or more. The 70 smut-free selections were again free from smut in 1926. In 1927, 33 of these lines were distributed to other stations for testing. Selection 1045 a3–1–4–1 (C. I. 2378) was outstanding in appearance and in yield at Ames, Iowa, in 1927, and continued to be productive at Ames and at stations in other states. This strain was named Carleton in 1931 in honor of the late Mark Alfred Carleton.

Carleton is an early, yellow, common oat, similar to Kherson or the parent strain Sixty-Day. It differs from most strains of Kherson in having more and stronger awns, a little larger panicle, and slightly longer lemmas. The culms usually are very hairy at the nodes like the Markton parent. Results of repeated tests at many stations have shown that Carleton is highly resistant to nearly all races of the oat smuts. Its superior characters are resistance to smut and *Fusarium*

TABLE 3.—*Yield of Fulton and Kanota oats grown at 10 experiment stations in the United States, 1936* and 1937.†*

Variety	Location of station and average acre yield, bushels										Average of 10 stations	Percentage of Kanota
	Arlington, Va.	Columbus, Ohio	Urbana, Ill.‡	Columbia, Mo.	Lincoln, Nebr.	Manhattan, Kans.	Denton, Tex.‡	Hays, Kans.	Akron, Colo.	Woodward, Okla.		
Fulton	64.1	61.3	46.9	49.2	37.2	57.4	34.4	30.6	41.2	21.7	44.4	123
Kanota	58.2	41.1	44.1	37.3§	26.3§	58.5§	30.0	22.4	28.1	15.6§	36.2	100

*COFFMAN, F. A. Results from the cooperative, coordinated oat breeding nurseries for 1936 and the uniform winter hardiness nurseries for 1936–37, together with average for previous years. U. S. Dept. Agr. Bur. Plant Ind., Div. Cereal Crops and Diseases [Unnumb. Pub.], 128 pp. July 15, 1937. [Mimeographed.]

†COFFMAN, F. A. Results from the cooperative, coordinated oat breeding nurseries for 1937 and the uniform winter-hardiness nurseries for 1937–38, together with average for previous years. U. S. Dept. Agr. Bur. Plant Indus. Div. Cereal Crops and Diseases [Unnumb. Pub.] 108 pp. May 28, 1938. [Mimeographed.]

‡Yield for 1936 only. §Average of several rows.

TABLE 4.—*Yield of Carleton and Markton oats grown in nursery rows and field plats at experiment stations in Oregon.**

Variety	C. I. No.	Acre yield, bushels												
		1926	1927	1928	1930	1931	1932	1933	1934	1935	1936	1937	1938	Average
Sherman Branch Experiment Station, Moro. (D. E. Stephens)														
Nursery plats:														
Carleton	2378	44.4	53.1	59.5	27.0	29.9	14.2	54.0	—	31.0	48.2	41.4	41.6	40.4
Markton	2053	37.2	35.1	56.2	24.8	27.3	9.7	36.6	—	25.4	43.5	37.3	35.0	33.5
Field plats:														
Carleton	2378	—	—	—	—	—	—	—	—	39.6	51.9	59.7	39.2	47.6
Markton	2053	—	—	—	—	—	—	—	—	33.8	51.9	53.7	36.9	44.1
Pendleton Branch Experiment Station, Pendleton (J. Foster Martin)														
Nursery plats:														
Carleton	2378	—	—	—	—	62.4	59.8	87.4	41.6	76.6	81.8	85.6	66.8	70.3
Markton	2053	—	—	—	—	60.3	56.5	81.8	28.4	58.9	85.8	71.8	67.1	63.8
Field plats:														
Carleton	2378	—	—	—	—	—	—	—	—	—	67.6	83.8	77.0	76.1
Markton	2053	—	—	—	—	—	—	—	—	—	77.0	78.3	77.5	77.6

*No yields were obtained at Moro in 1929 and 1934 because of severe drought. Data obtained cooperatively by the Oregon Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

culmorum, high yield, early maturity, and adaptation to dry-land conditions. It has no resistance to the rusts of oats.

Stanton (5) has listed Carleton as a superior strain. Several hundred bushels of seed of Carleton were distributed to farmers in 1937 and 1938 from the Sherman Branch Experiment Station, Moro, Oreg., from which station D. E. Stephens applied for its registration. Numerous nursery yield data on Carleton from many tests have been compiled by F. A. Coffman in annual mimeographed reports.[5] The annual and average yields of Carleton and other standard varieties for comparison obtained at the Sherman Branch Experiment Station, Moro, Oreg., the Pendleton Branch Station, Pendleton, Oreg., and other agricultural experiment stations in dry-farming areas, are presented in Tables 4 and 5.

TABLE 5.—*Yield of Carleton and certain standard oat varieties grown in replicated field plats at the dry-land experiment stations indicated.**

Variety	C. I. No.	Yield per acre, bushels							
		1932	1933	1934	1935	1936	1937	1938	Av.
U. S. Field Station, Sheridan, Wyo. (R. S. Towle)									
Carleton	2378	66.4	46.4	47.5	27.5	8.6	38.4	83.1	45.4
Markton	2053	69.3	49.3	51.6	16.0	8.0	23.5	85.3	43.3
Gopher	2027	70.5	38.9	46.4	25.2	4.0	33.2	80.8	42.7
Iogold	2329	67.0	36.7	47.5	28.1	4.6	34.9	83.1	43.1
Victory	560	45.2	40.1	37.8	13.2	1.7	20.1	76.8	33.6
Dickinson Substation, Dickinson, N. Dak. (R. W. Smith)									
Carleton	2378	30.3	15.6	9.1	36.8	0.3	9.1	16.9	16.9
Markton	2053	37.4	18.2	9.3	35.3	0.2	8.9	12.1	17.3
Gopher	2027	37.7	13.7	8.6	39.2	0.5	7.0	18.1	17.8
Victory	560	32.6	12.1	7.1	25.5	0.4	3.2	4.1	12.1
Northern Montana Branch Station, Havre, Mont. (M. A. Bell)									
Carleton	2378	—	—	—	35.4	3.7	7.8	63.5	27.6
Gopher	2027	—	—	—	34.4	2.4	6.3	61.5	26.2
Markton	2053	—	—	—	33.3	2.8	7.8	53.6	24.4
Idamine	1834	—	—	—	28.6	2.3	4.7	55.7	22.8
Swedish Select	134	—	—	—	30.2	0.7	3.7	49.5	21.0

*Data obtained cooperatively by the Divisions of Dry-Land Agriculture and Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Wyoming, North Dakota, and Montana Agricultural Experiment Stations.

BANNOCK, REG. NO. 86

Bannock (C. I. 2592) originated from a cross between Markton and Victory oats made in 1923 by G. A. Wiebe at the Aberdeen Substation, Aberdeen, Idaho. The F_1 hybrid was grown in the greenhouse at Arlington Farm in the winter of 1923–24. Beginning in 1924 successive generations of selections were grown at the Aberdeen Substation from smut-inoculated seed until 1928, when a group of the resistant selections was tested for yield in 15-foot nursery rows. One of these selections, row No. 4831, in 1928 (C. I. 2592), was named Bannock in 1938 after its smut resistance and high yielding ability had been

[5]Coffman, F. A. See footnote 2, Table 3.

proved in further tests at the Aberdeen Substation and experiment stations in other states. Bannock, therefore, is a product of the coordinated oat-breeding program carried on cooperatively by the Idaho Agricultural Experiment Station and experiment stations in other states and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Those besides the writer who had a part in the breeding of Bannock, are F. A. Coffman, Harland Stevens, John L. Toevs, G. A. Wiebe, L. L. Davis, A. E. McClymonds, and V. F. Tapke. Agronomists of the various experiment stations who tested Bannock and many sister selections are entitled to credit. Bannock was first introduced to farmers of southern Idaho in the spring of 1938, nearly 40,000 pounds of seed having been distributed from the Aberdeen Substation. Application for the registration of Bannock was made by Harland Stevens and John L. Toevs.

Bannock is a midseason white oat with resistance to most physiologic races of the oat smuts. This resistance should continue unless hitherto unknown new races of smut should spread and infect Bannock.

Bannock ripens at about the same time as the Victory parent, is somewhat shorter, and is about equal to it in quality. The straw of Bannock is fairly stiff and the grains have relatively few awns. The superior characters of Bannock are resistance to smut, high yield, white kernels, and high quality. Bannock has been tested in replicated plats at Aberdeen since 1933. The annual and average yields obtained are given in Table 6.

TABLE 6.—*Annual and average yield of Bannock and four standard oat varieties grown in replicated plats at Aberdeen, Idaho, 1933–38.*

Variety	C. I. No.	Acre yield, bushels						
		1933	1934	1935	1936	1937	1938	Av.
Bannock....	2592	138.8	118.8	140.9	118.3	112.9	154.0	130.6
Markton....	2053	142.5	110.9	135.9	122.5	109.5	143.5	127.4
Victory.....	2020	136.7	111.5	137.4	142.5	115.3	139.6	130.5
Idamine.....	1834	137.5	112.0	133.9	132.1	108.4	134.4	126.4
Abundance..	2038	137.1	115.4	135.2	140.0	121.4	136.7	131.0

TABLE 7.—*Average acre yield in bushels of Bannock and four standard oat varieties grown under irrigation in uniform nursery experiments for 2 to 9 years at the agricultural experiment stations indicated.*

Variety	C. I. No.	Aberdeen, Idaho (1929–37), 9 years	Bozeman, Mont. (1930–37), 8 years	Ft. Collins, Colo. (1930–37), 8 years	Logan, Utah (1932–37), 6 years
Bannock.......	2592	136.3	130.7†	91.5	122.7
Markton.......	2053	124.4	117.3	87.4‡	113.7‖
Victory........	——	123.2*	121.7	85.6§	109.9¶
Idamine.......	1834	125.1	110.1‡	——	104.1¶

*Six-year average.
†Yield of sel. 2592-1, two-year average.
‡Four-year average.
§Nine-year average of Colorado No. 37 substituted.
‖Eight-year average.
¶Seven-year average.

Bannock also has been tested in cooperative, coordinated uniform oat nurseries at other irrigated experiment stations in certain western states. Average acre yields of Bannock, Markton, and Victory, the two parent varieties, and Idamine obtained at the Aberdeen Substation, Aberdeen, Idaho, and the state agricultural experiment stations at Bozeman, Mont., Fort Collins, Colo., and Logan, Utah, as compiled by Coffman[6] are given in Table 7. Credit is due W. B. Nelson, D. W. Robertson, and R. W. Woodward of the state experiment stations at Bozeman, Mont., Fort Collins, Colo., and Logan, Utah, for their part in obtaining the original data on which these averages are based.

Further information on Bannock may be found in the literature on oats (1, 2, 3, 5).

LITERATURE CITED

1. ANON. Idaho growers to get new oats. Bannock hybrid developed at Aberdeen. Idaho Farmer, 56:119. 1938.
2. ———. New smut-resistant white oat comes from Aberdeen Substation. Univ. Idaho News Letter, 23:1–2. 1938.
3. FITZGERALD, O. A. New smut-resistant oat. Country Gent., 108:66. 1938.
4. STANTON, T. R. Registration of varieties and strains of oats, VII. Jour. Amer. Soc. Agron., 27:1001–1002. 1935.
5. ———. Superior germ plasm in oats. U. S. D. A. Yearbook, 1936: 347–414. 1936.
6. ———, STEPHENS, D. E., and GAINES, E. F. Markton, an oat variety immune from covered smut. U. S. D. A. Circ. 324. 1924.

[6]Coffman, F. A. See footnote 1, Table 3.

REGISTRATION OF IMPROVED WHEAT VARIETIES, XII[1]

J. Allen Clark[2]

ELEVEN previous reports present the registration of 55 improved varieties of wheat. In 1937, two varieties were registered, and as in former years, the previous registration was referred to:[3]

Three varieties have been approved for registration in 1938, as follows:

Varietal Name	Reg. No.
Nebred	321
Pilot	322
Thorne	323

NEBRED, REG. NO. 321

Nebred (Nebraska No. 1063, C. I.[4] 10094) was developed in cooperative experiments of the Nebraska Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The original selection was made in 1924 by T. A. Kiesselbach and Arthur Anderson from a plat of Turkey (S. Dak. 144, C. I. 3684) at Lincoln. The seed for the plat had been inoculated with *Tilletia levis*, and an epidemic of stem rust was created in the spring. Heads were selected from plants free of bunt and relatively free of rust. In succeeding years these selections were inoculated with bunt and only the resistant ones were continued. The testing work became cooperative in 1930, C. A. Suneson and K. S. Quisenberry successively representing the U. S. Dept. of Agriculture. Dr. T. A. Kiesselbach applied for registration.

Nebred is a winter wheat of the Turkey type. The spike is awned with glabrous glumes and has hard red kernels. It is rather winter hardy and midseason as to maturity.

In Table 1 yield data are presented comparing Nebred, Cheyenne, and Turkey at Lincoln. It will be seen that Nebred has outyielded Turkey but is not quite equal to Cheyenne. In the cooperative regional hard red winter wheat improvement program Nebred has been tested in the central district or stations in Kansas, Nebraska, and Colorado. In these tests it has been one of the highest yielding varieties at all stations.

Nebred was selected chiefly for resistance to bunt. In Table 2 data are presented which show that the variety is more resistant to forms of smut in the Great Plains than either Oro or Minturki, two com-

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 29, 1938.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Member of the 1938 Committee on Varietal Standardization and Registration, charged with the registration of wheat varieties.

[3]Clark, J. Allen. Registration of improved wheat varieties, XI. Jour. Amer. Soc. Agron., 29:1031–1032. 1937.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

TABLE 1.—*Comparative yields of Nebred and other standard winter wheats grown in plat tests (five replications) at Lincoln, Nebr., 1930–38.*

Variety	Yield in bushels per acre									
	1930	1931	1932	1933	1934	1935	1936	1937	1938	Av.
Nebred (new)	44.5	44.2	30.6	24.7	40.5	28.5	34.2	12.8	17.7	30.9
Cheyenne	47.4	48.1	38.0	29.3	43.1	24.0	31.8	14.0	13.7	32.2
Turkey	42.6	44.8	28.9	26.6	36.7	20.6	31.4	14.6	12.7	28.8

mercial varieties having considerable resistance. While Nebred is not resistant to all forms of bunt, it is resistant to those forms now known to be present in Nebraska.

TABLE 2.—*Average bunt infection of five varieties of winter wheats grown in uniform winter wheat bunt nursery in the Great Plains area, 1932–37.*

Variety	Average percentage bunt infection (52 station years)
Nebred	2.1
Oro	5.1
Minturki	6.3
Cheyenne	43.7
Kharkof	45.1

Nebred is not considered resistant to stem rust, but it seems to be able to produce a fairly good crop of grain in the presence of rust. This is probably due in part to some degree of earliness and a tendency to become infected with rust a little later than some other varieties. The variety is susceptible to leaf rust.

The milling quality of Nebred is very good, and the flour gives a good loaf of bread, although there is a slight tendency for a yellow color to be present in some years.

The variety was named in 1938 and released to farmers for fall seeding. About 1,100 bushels were available and all of this was seeded.

PILOT, REG. NO. 322

Pilot (N. No. 1098, C. I. 11428) was developed in cooperative experiments of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the North Dakota Agricultural Experiment Station, as well as other cooperating state stations in the regional hard spring wheat improvement program. Pilot is the result of a Hope×Ceres cross made under the direction of the writer by E. R. Ausemus in 1926 at the Northern Great Plains Field Station, Mandan, N. Dak. The selection resulted from stem rust inheritance studies made from the cross by Clark and Ausemus in F_3, 1928, and the strain entered nursery experiments in all North Dakota stations in 1931 and the Uniform Regional Nursery in 1932. It is the only hybrid strain that has been continued in that nursery from its start in 1932 to 1938, during which period 94 strains have been tested.

Results have been obtained from the regional nursery on Pilot wheat at from 9 to 17 stations for seven years, or a total of 96 station years. The strain N. No. 1098 entered plat experiments at the four North Dakota stations in 1933 and was a uniform variety at all cooperating stations in the spring wheat region by 1936. It has been included in the plat experiments for from 3 to 6 years at 19 stations, or a total of 76 station years. Its best performance has been at the Langdon Substation, Langdon, N. Dak., where, at the request of the writer, reselections were made in F_8, 1933, by G. S. Smith to provide foundation stock seed. From more than 100 selections grown in 1934, 80 were composited for increase and this stock was known as N. No. 1098-A.

In the bad rust year of 1935, many of the individual selections were still under test at Langdon and nine of the most resistant and highest yielding strains were composited as N. No. 1098-B. This seed is being increased separately at Langdon and about 80 bushels are now available. Certain of these nine strains have been continued in experiments at Langdon and Fargo and strains –13, –18, –28, and –59 appear more promising than the N. No. 1098-B. The seed of N. No. 1098-B was substituted for the regular N. No. 1098 for the Uniform Regional Nursery in 1936 and in plat experiments at most stations in 1938. One of the single line strains, –28, was substituted for the N. No. 1098-B in the Regional Nursery in 1938. Either it or a better one of the single line strains continued will be increased for the future distribution of Pilot seed. In the meantime, a bulk of the original N. No. 1098 and the N. No. 1098-A has been increased by E. J. Taintor, Superintendent of the Walsh County Agricultural and Training School, Park River, N. Dak., and from 78 acres grown in 1938 approximately 2,000 bushels are available for seeding in 1939.

Pilot is an awned spring wheat with white glabrous glumes and midsized (Cereslike) hard, red kernels. Its superior characters are resistance to both stem and leaf rust and to bunt. It is a high yielding wheat, especially in northeastern North Dakota, and has exceptionally good milling and bread making properties, ranking first among the new hybrid strains tested by the U. S. Dept. of Agriculture.[5] Messers. J. A. Clark and Glenn S. Smith applied for its registration.

Yields and other data upon which registration was based are shown in Tables 3 and 4.

THORNE, REG. NO. 323

Thorne (T. N. 1006, C. I. 11856) was developed by the Ohio Agricultural Experiment Station from a Portage×Fulcaster cross made at Columbus in 1917 by L. E. Thatcher. The selection known as T. N. 1006 was made in 1924 and reselections for furnishing foundation stock seed were made in 1934. In 1936, in the neighborhood of 200

[5]FIFIELD, C. C., and CLARK, J. A. Milling and baking experiments with hard red spring wheats, 1929–35. 28 pp. June 15, 1936. [Mimeographed.] For further information on Pilot wheat (Hope×Ceres, N. No. 1098, C. I. 11428) see the annual mimeographed reports, "Results of spring wheat varieties grown in cooperative plot and nursery experiments in the spring wheat region," by J. A. Clark from 1932 to 1937.

TABLE 3.—*Yield per acre, stem rust, and quality data on Pilot and standard varieties grown in nursery and plat experiments at the Langdon Substation, Langdon, N. Dak., 1931–38.*

Experiment and variety	1931	1932	1933	1934	1935	1936	1937	1938	Av.
				Yield per acre, bu.					
Nursery:									
Pilot (new)	25.2	27.7	17.9	19.2	14.3	9.9	28.4	22.9	20.7
Ceres......	16.8	27.0	19.1	19.6	0.7	12.5	12.9	3.2	14.0
Marquis...	12.0	25.7	18.9	18.8	0.0	10.5	7.7	0.0	11.7
				Stem rust, %					
Pilot (new)	2	T	0	T	25	0	5	1	4
Ceres......	25	15	3	7	65	0	65	85	33
Marquis...	60	30	12	15	100	0	80	100	50
				Yield per acre, bu.					
Plats:									
Pilot (new)	—	—	16.0	24.1	18.7	6.5	31.6	33.7	21.8
Hope......	—	—	15.0	21.3	15.5	5.8	30.1	30.0	19.6
Thatcher..	—	—	15.8	25.0	17.3	5.7	26.2	22.4	18.7
Ceres......	—	—	20.4	23.8	3.3	5.7	18.9	8.6	13.5
Marquis...	—	—	19.8	24.6	0.4	6.2	16.7	4.8	12.1
Reward....	—	—	14.0	15.9	2.4	0.7	19.4	10.4	10.5
				Stem rust, %					
Pilot (new)	—	—	0	1	15	0	10	5	5
Hope......	—	—	0	0	T	0	0	0	0
Thatcher..	—	—	0	1	10	0	10	5	4
Ceres......	—	—	1	5	80	0	65	85	39
Marquis...	—	—	3	15	95	0	80	100	49
Reward....	—	—	2	7	100	0	85	95	48
				Test weight, lbs.					
Pilot (new)	—	—	60.0	58.5	48.5	58.0	60.6	58.2	57.3
Thatcher..	—	—	59.5	59.0	51.0	55.5	59.1	57.5	56.9
Hope......	—	—	58.0	58.0	48.5	56.5	58.0	55.5	55.8
Ceres......	—	—	61.0	60.5	41.5	59.0	54.9	43.0	53.3
Marquis ..	—	—	60.0	60.0	40.5	58.5	53.0	42.5	52.4
Reward....	—	—	63.0	61.5	42.0	56.0	60.0	53.5	56.0
				Crude Protein Content, %					
Pilot (new)	—	—	14.8	15.6	16.0	18.3	15.2	14.5	15.7
Thatcher..	—	—	14.9	15.7	15.7	18.6	14.6	14.0	15.6
Hope......	—	—	14.3	14.7	16.0	—	—	—	—
Ceres......	—	—	13.9	15.5	15.8	18.0	13.0	—	—
Marquis...	—	—	13.7	14.1	—	18.0	—	—	—
Reward....	—	—	16.0	16.3	—	—	—	—	—
				Loaf volume, basic bake, cc					
Pilot (new)	—	—	653	693	571	699	650	643	652
Thatcher..	—	—	630	670	577	672	625	629	634
Hope......	—	—	577	531	543	—	—	—	—
Ceres......	—	—	577	568	697	835	592	—	—
Marquis...	—	—	583	513	—	723	—	—	—
Reward....	—	—	633	656	—	—	—	—	—
				Loaf volume, commercial bake, cc					
Pilot (new)	—	—	—	—	688	766	715	758	732
Thatcher..	—	—	—	—	673	764	670	737	711

TABLE 4.—*Average yield from plat experiments of Pilot, Thatcher, Ceres, Reward, and Marquis wheats at 19 experiment stations in 7 states during 3- to 6-year periods.*

State and station	No. years	Pilot	Thatcher	Ceres	Reward	Marquis
North Dakota:						
Langdon	6	21.8	18.7	13.5	10.5	12.1
Fargo	6	24.4	24.4	20.3	19.3	15.4
Mandan	6	9.8	10.9	6.9	7.1	4.9
Dickinson	6	7.9	6.6	6.7	4.7	5.1
Average	24	16.0	15.2	11.9	10.4	9.4
Minnesota:						
St. Paul	4	18.2	21.5	14.4	20.7	10.4
Waseca	4	32.1	30.5	21.1	23.8	13.8
Morris	4	25.0	28.5	15.2	19.9	11.0
Crookston	4	21.8	21.0	13.3	16.1	8.2
Average	16	24.3	25.4	16.0	20.1	10.9
South Dakota:						
Brookings	5	19.0	21.4	12.6	14.6	9.6
Highmore	3	6.6	7.1	7.2	5.3	4.1
Newell	3	11.2	13.6	11.0	6.8	11.1
Average	11	13.5	15.4	10.7	9.9	8.5
Montana:						
Bozeman	3	57.2	62.4	58.3	45.3	57.9
Moccasin	4	12.5	14.0	13.7	12.0	12.5
Havre	3	8.9	9.6	10.4	9.0	7.8
Average	10	24.8	27.2	26.1	21.1	24.7
Nebraska:						
Lincoln	3	10.2	11.0	10.5	10.1	5.7
North Platte	3	7.1	8.0	9.1	6.5	5.8
Alliance	3	9.2	9.8	9.9	9.9	6.8
Average	9	8.8	9.6	9.8	8.8	6.1
Wyoming:						
Sheridan	3	19.8	21.8	21.7	19.6	16.9
Colorado:						
Akron	3	9.8	10.3	9.9	12.9	8.2
Region:						
Weighted average	76	17.6	18.3	14.5	14.1	11.4

lines similar in appearance and performance were bulked together and increased as Thorne wheat.

Thorne is an awnleted, brown glumed variety of soft red winter wheat. It has the appearance of Portage (Poole) and the straw is exceptionally stiff, being superior to Trumbull in this important respect. The head is carried erect, and the grain is reasonably plump. In quality, it is similar to Trumbull and Fulhio, and acceptable to the soft wheat millers. Thorne has outyielded Trumbull and Fulhio in

TABLE 5.—*Comparative yields of Thorne, Trumbull, and Fulhio wheats at Wooster and average of Ohio stations, 1926–38.**

Variety	Wooster (Wayne County)							
	1926	1927	1928	1929	1930	1931	1932	1933
Thorne	61.5	46.9	44.8	44.0	43.6	50.8	26.9	52.0
Fulhio	58.7	46.9	34.8	40.5	40.7	47.4	22.8	48.7
Trumbull	56.3	45.7	32.8	40.3	39.8	47.3	21.5	51.5
Variety	1934	1935	1936	1937	1938	Total years	Average	Percentage of Trumbull
Thorne	—	—	40.1	49.6	58.5	11	47.2	113.2
Fulhio	—	—	—	37.2	52.7	10	43.0	103.1
Trumbull	—	—	35.6	37.1	51.1	11	41.7	100.0
Variety	Average of all stations							
	1926	1927	1928	1929	1930	1931	1932	1933
Thorne	61.5	46.9	44.8	33.7	31.4	46.9	28.5	36.5
Fulhio	58.7	46.9	34.8	32.0	31.5	44.3	26.2	32.7
Trumbull	56.3	45.7	32.8	31.2	30.2	44.2	24.9	32.8
Variety	1934	1935	1936	1937	1938	Total years	Average	Percentage of Trumbull
Thorne	34.7	39.4	33.2	33.5	42.1	107	36.7	108.9
Fulhio	32.4	36.0	—	32.4	36.9	100	34.4	102.1
Trumbull	33.1	36.4	29.8	31.6	37.8	107	33.7	100.0

*For further information on Thorne wheat, see Special Circular No. 55, Thorne Wheat, Ohio Agr. Expt. Sta., September 1938.

tests at 15 stations. The yield results, which are the basis for registration, at Wooster and the average for all 15 stations in Ohio are given in Table 5. C. A. Lamb, who made the selection, applied for the registration of Thorne wheat.

NOTE

PERFECT-FLOWERED BUFFALO GRASS (*BUCHLOE DACTYLOIDES*)

BUFFALO grass with perfect flowers borne on the staminate inflorescence was found in June, 1938, at College Station, Texas. Since this grass is one of the most important range grasses in Texas, the Agricultural Experiment Station started an intensive study with it in December, 1936. At that time, 1,000 seeds secured from Temple in the blackland region and a like number secured from Chillicothe in the rolling plains in western Texas were planted in flats in the greenhouse at College Station. Since there is a great deal of difference in the appearance of the plants from the two regions, plants from the blacklands have been termed the "Temple" strain and those from western Texas the "Chillicothe" strain.

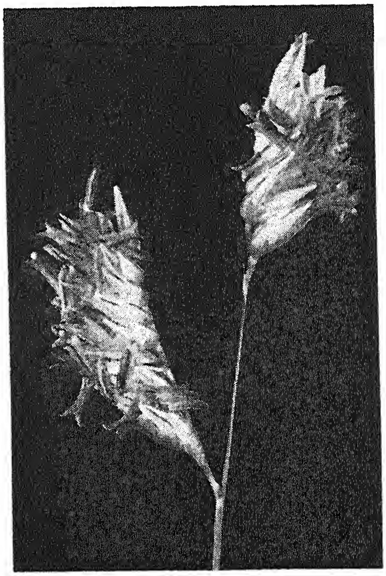


FIG. 1.—Normal staminate spike at the time of anthesis (natural size).

The germination was 46.6% for the Temple strain and 52.1% for the Chillicothe strain. These seedlings were transplanted into pots and, when fully established, 300 of the most vigorous plants of each strain were set in plats 4 feet square in the grass nursery. Exact and comprehensive notes have been kept of each individual plant and data have been secured on characters such as rate of growth, width and length of leaf, length of internode, winterhardiness, drought resistance, length of seed stalk of both male and female, and a number of other characteristics.

In making examinations of these data, we came upon a plant which produced perfect flowers on what was normally the staminate inflorescence. (See Figs. 1 and 2.) Later four other plants of a like nature were found. Microscopic examination shows beyond a doubt that the flowers are truly perfect. Examination of matured florets from these plants revealed several which produced what appear to be fully developed caryopses, though much smaller than normal seed produced by the female plant. The viability of these seeds has not yet been determined. That the pollen is functional is demonstrated by the fact that normal seeds have been obtained from crosses in which the perfect-flowered plant served as the pollen parent. Plant No. 534 is staminate and practically all of the inflorescence shows this peculiarity. Plant No. 45 was first recorded as a monoecious plant as both male

FIG. 2.—Staminate spike showing both anthers and stigmas at the time of anthesis (enlarged 4 times).

and female inflorescences were present. Later examination showed that some of the staminate spikes contained perfect flowers.

Just what practical application can be made of this discovery is problematical, but it is reasonable to assume that if this type of plant can be propagated, the question of gathering seed would doubtless be greatly simplified. Further intensive studies are being made with the plants, among them being their use as parents in controlled crosses. —R. L. HENSEL, *Texas Agricultural Experiment Station, College Station, Texas.*

BOOK REVIEWS

MICROPEDOLOGY

By Dr. Ing. Walter L. Kubiena, Ames, Iowa: Collegiate Press, Inc. XVI+243 pages, illus. 1938. $3.

THIS book represents the lectures the author gave as guest Professor of Soil Morphology at the Iowa State College during the year 1937 and is the result of his nine years' experience in the adaptation of the microscope to soils investigations. The book assumes a knowledge of general soils, soil microbiology, and microscopy and is devoted to the fundamental principles of microscopic pedology.

The material is presented in four parts. Part I presents the principles of micropedology, uses and development of microtechnic in other natural sciences. Part II treates of the technic of micropedology with chapters on incident light microscopes, the soil microscope, performance of micromanipulations, microscopic field investigations, soil sampling, soil preparations, fabric reactions, optical methods, and microchemical methods. The detailed procedures for micromanipulations are well illustrated by excellent drawings and photographs. Part III develops the principles of soil fabrics or the arrangement of the constituents of a soil in relation to each other. Part IV deals with biological soil microscopy by which is understood a study of living things in the soil and their activity in the microscopic dimensions as perceived by direct observation.

Dr. Kubiena has introduced a new concept in soil fabrics which is most interesting and promises to be of large value in the study of the genetic relationships of soils. (F. B. S.)

STATISTICAL METHODS

By George W. Snedecor. Ames, Ia.: Collegiate Press. XIII+388 pages, illus. 1938.

THIS work could very properly be called an enlarged edition because, while the book has been increased 47 pages, the amount of revision of the original text is relatively small. A number of sections have had additions of one or more paragraphs, but the bulk of new material is contained in 13 extra sections inserted at appropriate places throughout the book.

The following are the titles of the added sections: Ratios and percentages, rates and percentages, size of sample, regression and rates, correlation between mean and variance, proportional subclass numbers, disproportional subclass numbers, randomized blocks in several localities or seasons, perennial plants in randomized blocks, four or more variables in a single group, calculation of regression with four variables, tests of significance for betas.

While the additions to sections of the original edition are too numerous to discuss, mention should be made of the inclusion of methods for calculation of missing data and the figure in section 11.5. Table 13.5 has been changed from "The 5% and 1% Points for Multiple

Correlation Coefficients with Three Variables" to "The 5% and 1% Points for *r* and R."

All of this new material will be welcomed by agricultural and biological workers and increases the value of this useful book. The discussions relative to percentages, rates, and ratios are especially valuable in pointing out the possibility of misinterpretation of results where the data are expressed and analyzed in these forms. "Percentages are fruitful sources of error" so Dr. Snedecor has performed a service in calling the attention of workers to pitfalls to be avoided. The comments given in the review of the original edition (Vol. 29, page 1033, of this JOURNAL) apply with even more force to the revised edition. (F. Z. H.)

PLANT PHYSIOLOGY

By Nicoloi A. Maximov. New York: McGraw-Hill Book Co. Ed. 5 (Second English translation). XXII 473 pages, illus. 1938. $4.50.

THE text of the new edition of this book has been completely re-arranged. The major part of the discussion has been re-written and the results of recent new research has been included. Illustrations are ample and have been taken, in general, from publications in English.

The book fills a need primarily for class room use and the teaching of plant physiology in agricultural institutions. It meets this need well by the manner in which the text is arranged and by the use of agricultural plants as material. The opening chapters acquaint the student with the general nutrition and growth of plants. These chapters deal with the physico-chemical organization of the plant, including its chemical composition and basic metabolism, respiration, growth, carbon and nitrogen assimilation, absorption of mineral elements, water relations, and translocation of substances.

The closing chapters, as well as the foregoing, deal with the plant as a unit organism and bring out the problems that have a more direct bearing on agricultural production and practice. Herein are explained the resistance of plants to unfavorable environmental conditions, interrelations between different parts of the plant, vegetative propogation, physiology of the development of plants and processes during flowering and ripening of fruits and seeds, and the seasonal phenomena in the life of plants. A complete picture of plant life starting in with the germination of the seed and ending with processes dealing with reproduction and maturation of seeds is presented to the student.

The new edition should receive an even wider acceptance than previous editions by students and teachers of plant physiology in agricultural institutions. (O. A. R.)

FELLOWS ELECT FOR 1938

WILLIAM HENRY PIERRE

WILLIAM HENRY PIERRE, Iowa State College, Ames, Iowa. Born on a farm near Brussels, Wisconsin, August 2, 1898. B.S.A., University of Wisconsin, 1921; M.S., 1923; Ph.D., 1925. Assistant soil surveyor, Wisconsin State Soil Survey, 1919–1921; assistant soil surveyor, South Dakota State College, 1921–1922; associate soil chemist, Alabama Agricultural Experiment Station, 1925–1929; associate professor of agronomy, University of West Virginia, 1929–1936; professor of agronomy and head of department of agronomy and genetics, 1936–1938; professor of agronomy and head of department of agronomy, Iowa State College, 1938–.

Member of A.A.A.S., American Chemical Society, American Society of Plant Physiologists, Soil Science Society of America, International Society of Soil Science, American Society of Agronomy.

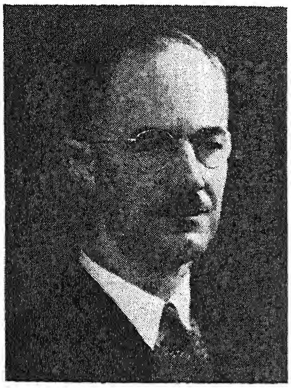
Dr. Pierre has been an active member of the Society, having served on various committees and having taken part in many of its annual programs. In 1931 he received the Chilean Nitrate of Soda Research Award. His most important scientific contributions have dealt with soil acidity, methods of determining the acid and base balance of fertilizers, buffer action of soils, relation of base saturation of soils and soluble aluminum to plant growth, and pasture management. His method of determining the acid and base balance of fertilizers was recently adopted as official by the A.O.A.C., and the method has already been instrumental in helping to bring about the use of fertilizers with a lower-acid forming tendency. Besides his research on specific problems and his teaching activities, Dr. Pierre has been actively interested in the practical problems of soil management and agriculture in general.

IDE PEEBLES TROTTER

IDE PEEBLES TROTTER, Head of the Department of Agronomy, Texas A. & M. College. Born at Brownsville, Tenn., December 12, 1895. B.A., Mississippi College, 1915; B.S., Mississippi A. & M. College, 1918; M.S., Mississippi A. & M. College, 1920; graduate work, University of Missouri, 1924–27, and University of Wisconsin, 1930–32; Ph.D., University of Wisconsin, 1933. Gamma Sigma Delta; Epsilon Sigma Phi; Alpha Gamma Rho; Pi Gamma Mu; Alpha Kappa Delta; Gamma Alpha. Extension Assistant Professor of Field Crops, University of Missouri, 1923–36; member of Missouri Cotton Allotment Board, 1933–34; since September 12, 1936, Head of the Department of Agronomy, Texas A. & M. College.

Dr. Trotter at Missouri was interested in the broad field of agronomy. His special employment was in extension teaching. For many years he labored constructively in the promotion of improved crop practices and soil management, and his efforts have left a lasting impression on Missouri agriculture.

CHARLES JULIUS WILLARD



CHARLES JULIUS WILLARD, Professor of Agronomy, Ohio State University, and Associate in Agronomy, Ohio Agricultural Experiment Station. Born at Manhattan, Kansas, February 14, 1889. B.S., Kansas State College, 1908; B.S.A., University of Illinois, 1910; M.S., University of Illinois, 1917; Ph.D., Ohio State University, 1926. Sigma Xi; Phi Kappa Phi; Alpha Zeta; Gamma Sigma Delta. Farmer, Brodford, Kansas, 1910–13, and Williamsburg, Virginia, 1913–16; Assistant Professor of Farm Crops, Ohio State University, 1917–26; Professor of Farm Crops, 1926–33; Professor of Agronomy, 1933—; Associate in Agronomy, Ohio Agricultural Experiment Station, 1926—.

Professor Willard is widely and favorably known for his contributions to the knowledge of life histories, ecology, physiology, comparative characteristics and responses of many forage crops. His studies of the life history phenomena and management of sweet clover were prime factors in raking that plant from the category of a "weed" to a forage and soil improvement crop of high rank.

Similarly his very extensive studies with alfalfa have provided a much-needed picture of its growth and management under humid conditions. Numerous investigations with the true clovers, of hay making problems, of life histories and control of weeds, and his analyses and investigations of factors and problems in securing successful seedings of forage crops, have earned him an enduring place in the agriculture of Ohio and the nation. He is author and co-author of an extensive and highly creditable series of publications which have been prepared with the utmost regard for adequacy and accuracy.

An energetic, analytical, active, cooperative, stimulating worker and coworker with intense interest in application and action programs as they are affected by and affect his studies. A conscientious teacher, whose former students long appreciate the wide extent and the thoroughness of his knowledge.

MINUTES OF THE THIRTY-FIRST ANNUAL MEETING OF THE SOCIETY

THE Thirty-first Annual Meeting of the Society was held in the Mayflower Hotel in Washington, D. C., November 16, 17, and 18. There were 653 registered at the meetings and considerably more than 700 in attendance at the sessions.

The general meeting of the Society was held jointly with the Soil Science Society of America on Thursday morning, November 17, President Truog and President A. M. O'Neal of the Soil Science Society presiding. The application of agronomy in farm planning was discussed by Dr. E. J. Utz of the Soil Conservation Service and "Soils, Crops, and People" was the subject of a paper by Dr. M. L. Wilson, Undersecretary of Agriculture.

The annual dinner was held on Thursday evening, with the address of the President, "Putting Soil Science to Work", as the feature of the occasion.

The Soil Science Society of America held meetings on Wednesday, Thursday afternoon, and Friday with programs on soil physics, soil chemistry, soil microbiology, soil fertility, soil morphology, and soil technology. The Crops Section had programs arranged on breeding, genetics and cytology, physiology, morphology and taxonomy, and miscellaneous subjects. Twenty-four half-day sessions were held in which 121 scientific papers were presented.

The Auditing Committee appointed by President Truog consisted of Dr. H. J. Harper and Dr. M. T. Jenkins. The Nominating Committee consisted of President Truog, Chairman, Dr. P. V. Cardon, Professor W. O. Collins, Dr. W. H. Pierre, and Professor A. T. Wiancko.

FELLOWS

Vice-President Garber announced the Fellows Elect and presented the diplomas. Those elected were Dr. W. H. Pierre, Dr. Ide P. Trotter, and Dr. C. J. Willard. (See pages 1047 to 1048.)

OFFICERS' REPORTS

REPORT OF THE EDITOR

TO SUMMARIZE briefly, the 1938 volume of the JOURNAL will not present any very marked differences from the 1937 volume, except that we have not fared quite so well this past year in respect to advertising, probably due to the general tightening up on such expenditures all along the business front. While our income from advertising has never been embarrassing, it is an important item in helping to meet certain overhead costs involved in JOURNAL publication and we take this opportunity to acknowledge our indebtedness to those advertisers who have patronized the JOURNAL through good times and bad and to point out to potential advertisers that the JOURNAL is well worth their consideration.

A total of 148 papers have been submitted to us during the past year. Of this number, 116 will have appeared in the JOURNAL with the publication of the December number. By way of record, it might be mentioned that of this 116

papers, 12 were presented at the annual meeting last year, including the two papers given on the general program, and one is the address of the President to which you have just listened and which will appear in the December JOURNAL.

We have 12 papers on hand, either awaiting publication or in the hands of reviewers, and 20 papers were returned to the authors for one reason or another. In addition, the 1938 volume will include 17 notes and 24 book reviews.

So much, then, for the make-up of Volume 30, except to express again, as we have in previous reports, our indebtedness to those who serve the JOURNAL and the Society so faithfully and so conscientiously in reviewing the papers submitted to us for publication.

One important responsibility was added to our office during the past year in the transfer of the stocks of the proceedings, journals, bulletins, etc., of the several agronomic organizations represented here tonight. In other words, we now have under one roof in Geneva, N. Y., all of the surplus copies of the JOURNAL of the American Society of Agronomy, the BULLETIN of the American Soil Survey Association, the PROCEEDINGS of the First International Congress of Soil Science, and the PROCEEDINGS of the Soil Science Society of America. These stocks are stored in a semi-fireproof building which, in turn, is protected with a sprinkler system, and are covered with a comprehensive insurance policy against loss from fire or damage from smoke or water, for as you will note from figures which appear in the Treasurer's report, these reserve stocks represent a very considerable potential income.

This change has necessarily incurred a considerable increase in the clerical work of the Editor's office. Since we assumed this duty early in the year, we have filled to date 5 orders for sets of the PROCEEDINGS of the First International Soil Science Congress, 13 orders for BULLETINS of the Soil Survey Association, 175 orders for back numbers of the JOURNAL of the American Society of Agronomy, and 223 orders for the PROCEEDINGS of the Soil Science Society.

We have now completed ten volumes of the JOURNAL since the publication in 1929 of the cumulative subject and author index for the first twenty volumes. A cumulative index of Volumes 21 to 30, inclusive, is ready to go to the printer, or will be with the paging of the December issue, and we wish to recommend to the Executive Committee at this time that this index of Volumes 21 to 30 be published as soon as possible. Following the procedure adopted with the publication of the index for the first twenty volumes of the JOURNAL, we recommend further that this new index be offered for sale by the Society at a price sufficient to meet the cost of publication and mailing.

I should like to close this report with a word of appreciation for one who from the founding of this Society down to the day of his death a few weeks ago maintained an active interest in all things pertaining to agronomy and who was particularly helpful in his unfailing interest in the JOURNAL. I refer to Dr. T. L. Lyon, for many years Chairman of the Editorial Advisory Committee. His counsels aided us immeasurably in weathering many difficult situations confronting the JOURNAL in recent years. Doctor Lyon was also the Society's Historian, and to his successor in this office will fall the privilege of inscribing his name high among those whom the Society would honor.

Respectfully submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society since the last annual report are summarized briefly as follows:

Membership last report		1,213
New members, 1938	145	
Reinstated members	37	
Total increase	182	
Dropped for non-payment of dues	134	
Resigned	27	
Died	4	
Total decrease	165	
Net increase		17
Membership, October 31, 1938		1,230

The subscription list has been increased during the year as the following figures will indicate:

Subscriptions, last report		649
New subscriptions, 1939	119	
Subscriptions dropped	108	
Net increase		11
Subscriptions, October 31, 1938		660

The paid up membership and subscription list by states and countries is as follows:

	Members	Subscriptions		Members	Subscriptions
Alabama	12	1	Nevada	2	1
Arizona	10	2	New Hampshire	3	1
Arkansas	12	3	New Jersey	16	3
California	35	10	New Mexico	7	2
Colorado	15	2	New York	50	15
Connecticut	11	3	North Carolina	16	3
Delaware	3	1	North Dakota	10	1
District of Columbia	77	5	Ohio	48	3
Florida	21	2	Oklahoma	14	5
Georgia	13	4	Oregon	12	2
Idaho	9	1	Pennsylvania	22	8
Illinois	50	11	Rhode Island	7	1
Indiana	25	3	South Carolina	17	2
Iowa	49	3	South Dakota	10	1
Kansas	46	2	Tennessee	14	2
Kentucky	11	5	Texas	47	8
Louisiana	16	3	Utah	14	7
Maine	5	1	Vermont	3	1
Maryland	17	5	Virginia	23	1
Massachusetts	9	3	Washington	21	4
Michigan	21	6	West Virginia	5	1
Minnesota	28	4	Wisconsin	36	1
Mississippi	11	4	Wyoming	6	1
Missouri	21	5			
Montana	8	5	Alaska	0	1
Nebraska	28	2	Hawaii	9	13

	Members	Subscriptions
Philippine Islands	1	2
Puerto Rico	4	3
Africa	4	24
Argentine	8	9
Australia	2	25
Brazil	1	5
British West Indies	1	1
Canada	20	42
Cuba	2	2
Ceylon	0	3
Chile	1	1
China	6	19
Columbia	1	1
Czechoslovakia	0	1
Denmark	2	1
Dutch East Indies	0	5
Egypt	2	1
England	0	15
Estonia	0	1
Fed. Malay States	1	4
Fiji	0	1
Finland	0	1
France	1	13
Germany	3	10
Greece	3	2
Haiti	1	0
Holland	2	2
Honduras	2	1
Hungary	1	0
India	4	21
Indochina	0	1
Ireland	0	2
Italy	0	10
Japan	3	86
Jugoslovia	0	2
Mauritius	0	1
Mesopotamia	1	1
Mexico	2	1
Morocco	0	1
New Zealand	0	5
Norway	0	2
Nova Scotia	1	0
Palestine	2	0
Panama	1	0
Persia	1	0
Peru	0	4
Poland	0	2
Portugal	0	4
Roumania	0	1
Scotland	3	1
Siam	2	1
Spain	0	1
Sweden	0	4
Switzerland	1	0
Turkey	1	0
Uruguay	1	0
U. S. S. R.	7	84
Wales	0	3
	1,074	617

The number dropped for non-payment of dues is smaller than it was last report and represents largely those who have switched from the JOURNAL to the PROCEEDINGS. The number resigned this year was exactly the same as the number resigned last year. The large drop list among the subscriptions came principally from China and Japan. The list of paid up members and subscriptions shows that we have 156 members and 43 subscriptions whose dues are in arrears. Notices and bills have been sent to all of these. We hope they will pay their dues and continue with the Society.

The special representatives of the Society have been of material assistance in bringing in new members during the year. Special mention should be made of the efforts of Doctors Aamodt, Keim, Trotter, Myers, Obenshain, Sturgis, and H. K. Wilson for the aid they have given the Society in this work. The Society is very greatly indebted to these men and all others who have given us help during the year and we want to thank you.

The work in the Secretary's office has increased enormously over what it was a few years ago. The Treasurer's report this year shows about 25% increase in the funds handled over that of last year. All publications of the Society have been concentrated at Geneva and this will permit us to give you much more efficient service than formerly when these publications were located at several different places. However, it does require some time to relay your orders to Geneva and some delay is necessary in making shipment. We have tried to keep things moving but when delay has been occasioned you have been patient and charitable and we appreciate it. I am especially grateful to the officers and members of the Society for their splendid cooperation in handling the details and arrangements for the program and annual meeting. To you credit is due for the measure of success we have made.

F. B. SMITH, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year November 1, 1937 to October 31, 1938.

RECEIPTS

Miscellaneous	$ 208.44
Advertising income	618.07
Reprints sold	1,584.17
Journals sold	183.33
Subscriptions, 1938	2,452.78
Subscriptions, 1937	59.95
Subscriptions, 1938, new	589.22
Subscriptions, 1939	165.20
Dues, 1938	4,135.00
Dues, 1937	233.00
Dues, 1938, new	750.02
Dues, 1939	109.50
Sale of Soil Survey Association Bulletins	44.85
Miscellaneous, S. S. S. A.	333.94
Sale of Proceedings, Vol. I, 1936	597.32
Dues and subscriptions, S. S. S. A., 1938	2,813.25
Dues and subscriptions, S. S. S. A., 1939	18.50
Membership only, S. S. S. A., 1938	41.50
Membership only, S. S. S. A., 1939	1.50
International Society of Soil Science endowment fund	2,789.32
Sale of Proceedings First International Congress of Soil Science	37.70
Fees, I. S. S. S., 1938	707.40
Fees, I. S. S. S., 1938, new	95.00
Fees, I. S. S. S., 1937	34.85
Fees, I. S. S. S., 1939	5.00
Total receipts	$18,608.81
Balance in cash, November 1, 1937	3,117.61
Total income	$21,726.42

DISBURSEMENTS

Printing the Journal, cuts, etc	$ 8,758.98
Salary Business Manager and Editor	738.89
Postage (Business Manager and Secretary)	186.75
Printing, miscellaneous	461.36
Express on Journals and Proceedings	32.39
Mailing Clerk and stenographic	901.63
Refunds, checks returned, etc	151.43
Miscellaneous, expenses annual meetings, freight and mailing publications	1,194.18
S. S. S. A. expenses, printing Proceedings, etc	3,401.07
I. S. S. S. expenses, fees to Dr. Hissink, etc	926.10
Purchase of savings bond, I. S. S. S. endowment fund	2,250.00
Total disbursements	$19,002.78
Balance on hand, November 1, 1938	2,723.64
Balance in Trust Certificates	410.88
Balance in Savings Bond	2,250.00
Total balance in account	5,384.52
Balance in cash on hand	2,723.64

F. B. SMITH, *Treasurer*

AUDITING COMMITTEE

The books were examined and all accounts found in order as reported by the Treasurer.

H. J. HARPER M. T. JENKINS

COMMITTEE REPORTS

BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE Committee has compiled a bibliography of 65 titles of the more important contributions on the methodology and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography previously published in the JOURNAL (Vol. 25:811–828, 1933; and the additions in Vol. 27:1013–1018, 1935; Vol. 28:1028–1031, 1936; Vol. 29: 1042–1045, 1937).

ADDITIONS TO BIBLIOGRAPHY ON STANDARDIZATION OF FIELD EXPERIMENTS

ATKINS, I. M. A simplified method for testing the lodging resistance of varieties and strains of wheat. Jour. Amer. Soc. Agron., 30:309–313. 1938.

BARTLETT, M. S. Some examples of statistical methods of research in agriculture and applied biology. Jour. Roy. Statis. Soc., Sup. 4:137–183. 1937.

————. The approximate recovery of information from replicated field experiments with large blocks. Jour. Agr. Sci., 28:418–427. 1938.

BATEN, W. D. A formula for reducing the computations necessary to find the variance of a set of averages. Jour. Agr. Res., 55:575–580. 1937.

BLISS, C. I. The transformation of percentages for use in the analysis of variance. Ohio Jour. Sci., 38:9–12. 1938.

CAMPBELL, R. S. Problems of measuring forage utilization on western ranges. Ecology, 18:528–532. 1937.

CAROLUS, R. L., HESTER, J. B., and BLUME, J. M. The reliability of rapid chemical plant tests as a means of diagnosing fertilizer deficiencies in vegetable crops. Amer. Fert., 89:7–8, 24. 1938.

COCHRAN, W. G. A catalogue of uniformity trial data. Jour. Roy. Statis. Soc., Sup. 4:233–253. 1937.

————. Some difficulties in the statistical analysis of replicated experiments. Emp. Jour. Expt. Agr. 6:157–175. 1938.

————. Recent advances in mathematical statistics. Recent work on the analysis of variance. Jour. Roy. Statis. Soc. 101:434–449. 1938.

COMRIE, L. J., HEY, G. B., and HUDSON, H. G. The application of Hollerith equipment to an agricultural investigation. Jour. Roy. Statis. Soc., Sup. 4: 210–224. 1937.

CROWTHER, F., and BARTLETT, M. W. Experimental and statistical technique of some complex cotton experiments in Egypt. Emp. Jour. Expt. Agr. 6:53–68. 1938.

DAWSON, C. D., and DORN, M. V. Plant chemiculture. A guide to experiments in growing plants without soil. 2 ed. Los Angeles. Pacific Carbon and Printing Co. 1938.

DAY, B., and FISHER, R. A. The comparison of variability in populations having unequal means. An example of the analysis of covariance with multiple dependent and independent variates. Ann. Eugen. Cambridge 7:333–348. 1937.

EDGAR, J. L. Strawberry cultivation studies.—II, Variability in individual plant size and cropping, with special reference to area and shape of plots for field experiments. Jour. Pomol. and Hort. Sci. 16: 91–100. 1938.

ELLIS, C., and SWANEY, M. W. Soilless growth of plants, use of nutrient solutions, water, sand, cinder, etc. New York Reinhold Pub. Corp. 1938.

FORBES, E. B. Procedure in pasture research. Amer. Soc. Anim. Prod. Proc. 1936: 32–37. 1937.

FORESTER, H. C. Design of agronomic experiments for plats differentiated in fertility by past treatments. Iowa Expt. Sta. Res. Bul. 226. 1937.

GILBERT, S. M. Planning field experiments on Coffea arabica. Trop. Agr. (Trinidad) 15:16–18. 1938.

————. Plot size in field experiments with Coffea arabica. Trop. Agr. (Trinidad) 15:52–55. 1938.

[GOSSET, W. S.] Comparison between balanced and random arrangements of field plots, by "Student". Biometrika 29: 363–379. 1938.

GOULDEN, C. H. Modern methods for testing a large number of varieties. Canada Dept. Agr. Tech. Bul. 9. 1937.

HAINES, W. B. Manuring Hevea.—II, Revision of experimental results by means of a sampling method for yield. Emp. Jour. Expt. Agr. 6:11–19. 1938.

HOBLYN, T. N., and EDGAR, J. L. A study of the technique of variety trials, as illustrated by the comparative yields of four black currant varieties grown in three different localities. Jour. Pomol. 15:326–337. 1938.

HROMÁDKO, J. Humusovélátky jako strojená hnojiva v přesných polních pokusech (Humusstoffe als künstliche düngemittel in exakten feldversuchen). Sbornik Ceskoslov. Akad. Zemed. 13:8–18. 1938. Ger. abs.

ISIKAWA, M., KAWAE, Y., and SUENOBU, T. Study of yield estimation of missing plot in field experiments with soybean. 1–2. Res. Bul. Agr. Expt. Sta. So. Manchuria Railw. Co. 23:1–62. 1937. 1, Influence of missing plot on the yield of adjacent plants. 2, Influence of road on the yield of adjacent plants. (In Japanese).

JODON, N. E., and BEACHELL, H. M. Row spacing and rate of seeding for rice nursery plats. Jour. Amer. Soc. Agron. 30:212–219. 1938.

KEMP, W. B. Separating a generalized interaction into components. Jour. Amer. Soc. Agron. 30:419–424. 1938.

KLAGES, K. H. W. Trend studies in relation to the analysis of yield data from rotation experiments. Jour. Amer. Soc. Agron. 30:624–631. 1938.

KUHNKE, A. Saatechnische leinversuche. Pflanzenbau 14:81–99. 1937.

LANDER, P. E., NARAIN, R., and SINGH, A. Soil uniformity trials in the punjab.—I. Ind. Jour. Agr. Sci. 8:271–307. 1938.

LOVE, H. H., and CRAIG, W. T. Investigations in plot technic with small grains. N. Y. Cornell Agr. Expt. Sta. Mem. 214. 1938.

LUNDEGARDH, H. The triple-analysis method of testing soil fertility and probable crop reaction to fertilization. Soil Sci. 45:447–454. 1938.

NEYMAN, J., and PEARSON, E. S. Note on some points in "Student's" paper on "Comparison between balanced and random arrangements of field plots." Biometrika 29:380–388. 1938.

————. Lectures and conferences on mathematical statistics. Washington, D. C. U. S. D. A. Grad. School. 1938.

OPSOMER, J. E. Notes techniques sur la conduite des essais avec plantes annuelles et l'analyse des résultats. Pub. Inst. Nat. Étude Agron. Congo Belge Sér. Scient. 14. 1937.

PAGE, H. J. Nonsense, common-sense, and statistics in field experiments with rubber trees. Planter (Kuala Lumpur) 18:378–386. 1937.

————. The uses of statistics in field experiments with rubber trees. Jour. Rubber Res. Inst. Malaya 8:197–216. 1938.

PEARSON, E. S. Some aspects of the problem of randomization.—II, An illustration of "Student's" inquiry into the effect of "balancing" in agricultural experiments. Biometrika 30:159–179. 1938.

PECHANEC, J. F., and PICKFORD, G. D. A weight estimate method for the determination of range or pasture production. Jour. Amer. Soc. Agron. 29:894–904. 1937.

PITMAN, E. J. G. Significance tests which may be applied to samples from any populations.—III, The analysis of variance test. Biometrika 29:322–335. 1938.

REYNOLDS, F. S., and CALDWELL, A. E. Measuring crop yields on a community scale. Jour. Amer. Soc. Agron. 30:635–643. 1938.

SALMON, S. C. Generalized standard errors for evaluating bunt experiments with wheat. Jour. Amer. Soc. Agron. 30:647–663. 1938.

SHAW, F. J. F. A handbook of statistics for use in plant breeding and agricultural problems. Dehli, Manager of publications. 1936.

SMITH, G. S. Gummed-paper tape for space-planting wheat. Jour. Amer. Soc. Agron. 30:348–352. 1938.

SMITH, H. F. An empirical law describing heterogeneity in the yields of agricultural crops. Jour. Agr. Sci. 28:1–23. 1938.

STOECKELER, J. H., and KLUENDER, W. A. The hydraulic method of excavating the root systems of plants. Ecology 19:355–369. 1938.

TANG, Y. Certain statistical problems arising in plant breeding. Biometrika 30: 29–56. 1938.

TING, C. L. A study of field technic with corn. Nung Hsueh Ts'ung k'an (Agr. Res. Col. Agr. Nat. Centr. Univ.) Nanking 3(2):47–94. 1936. (Chinese with Eng. abs.).

TIPPETT, L. H. C. The methods of statistics—an introduction mainly for experimentalists. 2 ed. London. Williams and Norgate, Ltd. 1937.
VINALL, H. H., LUSH, R. H., SHEETS, E. W., ET AL. Preliminary presentation on pasture investigations technique. U. S. D. A. Soils Cons. Serv. 1936.
VISSER, W. C. De ongelijkmaticheid van den grond en de nauwkeurigheid bij proefvelden. Verslag. Landb. Onderz. Rijkslandbouwproefst. Groningen 43(7) A:77–122. 1937. Ger. abs.
VRIES, D. M. DE. Methods used in scientific plant sociology and in agricultural botanical grassland research. Herbage Rev. Imp. Bur. Gen. 5:187–193. 1937.
————. Methods of determining the botanical composition of hayfields and pastures. Intern. Grassland Cong. Gt. Brit., Rep. 4:474–480. 1937.
————. Das serienprinzip in feldversuchen.—III, Bodenk. u. Pflanzenernähr 8:73–77. 1938.
WATSON, A. N., and DAVIS, R. L. The statistical analysis of a spacing experiment with sweet corn. Jour. Amer. Soc. Agron. 30:10–17. 1938.
WELCH, B. L. On the z-test in randomized blocks and Latin Squares. Biometrika 29 (I & II):21–52. 1937.
————. The significance of the difference between two means when the population variances are unequal. Biometrika 29:350–362. 1938.
WEST, O. The significance of percentage area determinations yielded by the percentage area or density list method of pasture analysis. Jour. Ecol. 26: 210217. 1938.
WILKINS, F. S., and HYLAND, H. L. The significance and technique of dry matter determinations in yield tests of alfalfa and red clover. Iowa Expt. Sta. Res. Bul. 240. 1938.
WISHART, J. Field experiments of factorial design. Jour. Agr. Sci. 28:299–306. 1938.
YATES, F. A further note on the arrangement of variety trials: Quasi-Latin squares. Ann. Eugen. Cambridge 7:319–332. 1937.
————. Applications of the sampling technique to crop estimation and forecasting. Trans. Manchester Statis. Soc. 1935–37 [article 2]. 1937.
YULE, G. U. An introduction to the theory of statistics. 11 ed. London. Charles Griffin and Co., Ltd. 1937.
————. Richtlinien für die durchführung von sortenversuchen. Reichsnährstand, Berlin. 1936.

F. R. IMMER H. M. TYSDAL
J. T. MCCLURE H. M. STEECE, *Chairman*

EXTENSION PROGRAM

THE Committee suggests that each year as the chairmen of the soils and crops sections of the American Society of Agronomy contact workers in the various states and in the U. S. Dept. of Agriculture with regard to subjects for presentation before the meetings of the Society, that they be requested to ascertain if the particular piece of investigational work to be reported upon is developed to the point where it is ready for practical application.

If the work is ready for application, we suggest that an extension worker present the extension application as a part of the same program.

We also suggest that every other year the extension agronomists hold a half day session on problems related to the application of their programs in the field.

E. R. JACKMAN J. S. OWENS
EARL JONES W. F. WATKINS
J. C. LOWERY O. S. FISHER, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

THREE varieties of wheat and three varieties of oats were registered during the year. The wheat varieties are as follows:

Nebred, Reg. No. 321, developed in cooperative experiments at the Nebraska Station.

Pilot, Reg. No. 322, developed in cooperation with the stations in the Northern Great Plains.

Thorne, Reg. No. 323, developed by the Ohio Agricultural Experiment Station.

The oat varieties are as follows:

Fulton, Reg. No. 84, developed in cooperative experiments at the Kansas Station.

Carleton, Reg. No. 85, developed in cooperative experiments at the Oregon Station.

Bannock, Reg. No. 86, developed in cooperative experiments with the Idaho Station.

Cooperation in each instance involved the U. S. Dept. of Agriculture and the stations named.

During the year the Committee gave further consideration to the preparation of standards for the registration of grain sorghums, which registration has already been approved by the Society. Preliminary consideration was given to plans for the registration of alfalfa, these plans to be submitted to the Society at a later date.

Description of the above varieties and the yield and other records that form the basis for registration will be published in the JOURNAL.

H. B. BROWN	H. K. HAYES	T. R. STANTON
J. ALLEN CLAREK	W. J. MORSE	G. H. STRINGFIELD
E. F. GAINES	J. H. PARKER	M. A. MCCALL, *Chairman*

PASTURE IMPROVEMENT

THE work of your Joint Committee on Pasture Improvement during the last year has centered upon activities designed to bring about fuller consideration of the comparative nutritive value and relative cost of forage and other crops.

To this end your Committee cooperated in the formulation of a program devoted to this subject in connection with the meetings of the American Association for the Advancement of Science held in Ottawa, Canada, last June.

As a result of that discussion it was deemed advisable to hold a round table discussion on the same subject as a part of the program of the American Society of Agronomy in Washington, D. C., November 18. The purpose of this round table was to consider the problems involved and to define a proposed procedure aimed at (a) the compilation of available data, and (b) at the clarification of the objectives of work remaining to be accomplished in this field. Discussion leaders represented the viewpoints of agronomists, animal and dairy production specialists, and extension workers.

The proposed joint plan of attack agreed upon follows:

1. Invite full participation through properly designated individuals or committees of the American Society of Animal Production, the American Dairy Science Association, the American Society of Agronomy, and the Canadian Committee on Pasture and Hay.
2. Organize a central committee (a) to direct action, (b) act as clearing house, and (c) prepare joint reports for approval by respective organizations.
3. Secure approval by respective organizations of joint reports.
4. Prepare joint reports for suitable publication and distribution.

Suggestions were made that the American Farm Economics Association, the Soil Science Society, and possibly some other agencies be included.

P. V. Cardon was authorized to communicate with the various societies indicated and through them initiate joint action.

O. S. Aamodt
B. A. Brown
R. D. Lewis
D. R. Dodd
H. D. Hughes
George Stewart
Paul Tabor
John Abbott
P. V. Cardon, *Chairman*

STUDENT SECTIONS

With the recent addition of New Mexico State College and Virginia Polytechnic Institute, 18 institutions now have chapters of the Student Section of the American Society of Agronomy. A meeting of representatives of the various chapters has been arranged at the time of the Crops Judging Contest in connection with The International Grain and Hay Show in Chicago.

Fourteen essays on the subject "Contributions of Agronomic Research to Agricultural Progress" were judged by the following committee: A. L. Frolik, Karl S. Quisenberry, and Karl Manke of Nebraska; J. W. Zahnley of Kansas; J. B. Peterson of Iowa; and G. H. Dungan and O. H. Sears of Illinois.

The first three winners will receive expense money up to a total of $50 each to permit them to attend the International Grain and Hay Show in Chicago. In addition each man will receive an appropriate medal and a year's subscription to the Journal of the American Society of Agronomy. The winners of 4th, 5th, 6th, and 7th, places will receive cash prizes of $20, $15, $10, and $5, respectively.

The authors of the first ten papers in order are: Maurice Peterson, Nebr.; Hilbert A. Grote, Kans.; Ogden C. Riddle, Nebr.; Robert E. Daniell, Nebr.; Frank A. Fieber, Ill.; Noel Hanson, Minn.; J. Richard Moore, Kans.; Russell H. Gripp, Kans.; Harold H. Mies, Ill.; and A. J. Fisher, Ill.

It is recommended that the abstracts of the first three papers be published in the Journal of the Society. The committee proposes that the Society continue to sponsor the essay contest during the coming year.

G. H. Dungan
A. L. Frolik
J. B. Peterson
J. W. Zahnley
H. K. Wilson, *Chairman*

CONTRIBUTIONS OF ALFALFA RESEARCH TO AGRICULTURAL PROGRESS

By Maurice Peterson, Univ. of Nebraska

The importance of alfalfa hay in the United States can be determined by observing the fact that it represents the greatest annual tonnage production of any kind of hay. Although attempts were made to grow alfalfa in colonial times, it really did not prove successful until 1854 when it was introduced into California from Chile. Acreage increased rapidly and within half a century it was grown throughout the United States where it was originally adapted. Since that time however, the acreage increase has been most rapid in the north where winter hardiness was a factor and in the east where unfavorable soil conditions were to be dealt with. This increase could not have been accomplished except for the research man.

The establishment of alfalfa on unadapted soils was important because the greatest need for this legume hay was in the eastern and northern dairy states where alfalfa was unadapted. One of the first pieces of research on alfalfa involved the discovery of the symbiotic relationship of bacteria and the legume plant. Upon this discovery was hinged the forthcoming work on bacterial strains, their acid tolerance, and the practical aspects of inoculation and of liming to reduce soil acidity. Although work on mineral deficiencies for alfalfa has not been extensive, it has nevertheless been responsible for the establishment of the crop on certain areas where it otherwise would not grow.

Many cultural practices have been found which helped greatly to increase the popularity of the crop. Seed bed preparation is an important problem in securing stands. The advisability of using a nurse crop depends upon the part of the country, season of the year, and other factors. The most popular nurse crops are wheat, oats, rye, flax, and barley. Application of lime and manure have helped greatly to secure stands in some localities.

Time of cutting and too frequent cuttings have been found to decrease winter hardiness and crop yields. This work has been substantiated by the plant physiologist relating to storage of organic food reserves, especially during the fall season. Winter protection afforded by fall top growth is a factor for reducing winter killing.

Crop sequence has an effect upon yields because of alfalfa's utilization of accumulated subsoil moisture which is usually not replaced for a period of many years under normal crop rotation in the dry farming areas. In areas of abundant winter rainfall, however, it has been found necessary to provide drainage to prevent killing out of stands.

Variety recognition has been comparatively recent. Most of the varieties grown at the present time are the results of testing of introduced and selected strains of alfalfa. Illustrations of this are Cossock, Ladak, Turkestan, and Grimm alfalfas. These varieties vary greatly in their desirable characteristics. The part of the country where a variety is used depends upon the limiting factor in crop production in that area. Some of the things varieties are selected for are superior yield and quality, wilt resistance, cold resistance, insect resistance and resistance to blackstem disease. Varieties or strains are now in existence which are strong in one or more of these factors. The plant breeder is now trying to recombine the desirable characters of two or more strains into one variety. Considerable recent work has been done along these lines and this introductory work has opened up a field with unlimited future possibilities.

CONTRIBUTIONS OF AGRONOMIC RESEARCH TO AGRICULTURAL PROGRESS

By Hilbert A. Grote, Kansas State College

PLANT research plays an important role in keeping mankind in stride with the ever varying traits of nature. Agronomic research workers have accomplished much in establishing a more stable agriculture and continuing it as such. Through introduction, selection, and crossing, adapted crops have been established in most sections of the country. New uses have been found for the old crops, as soybeans, now valuable for oil, food, and industrial purposes.

A phase of research being given much attention recently is that of weed control. The plant investigators are endeavoring to find the most successful and economical means of eradicating the more persistent weed pests. Much work is being

done at the present time on Field Bindweed, *Convolvulus arvensis L.,*. A comparatively few years ago this weed was of little importance, but it has been spreading at such an alarming rate that today it is considered the most troublesome of all weeds in many regions of the United States.

That this weed can be successfully eradicated has been definitely proved by experiments conducted at various experiment stations throughout the country. Clean cultivation is by far the most dependable and economical of all eradication methods now known.

The death of bindweed under fallow treatment is primarily due to a starvation process. When the above-ground parts of the bindweed plant are cut off, it is forced to draw upon the food reserves in the roots to produce a new top growth. When the cutting-off process is repeated each time before the top growth reaches the proper stage to replenish the supply, the food reserves are gradually exhausted. When cultivation at the proper intervals is continued long enough the death of the plant always results. Advantages of clean cultivation are that it is cheaper, that it usually increases the productivity of the soil, and it is more dependable than other treatments. Investigations show that bindweed may be eradicated for approximately ten dollars an acre, whereas, the cost of eradication by the use of sodium chlorate will range from thirty-six dollars to fifty-two dollars per acre. Practically all recent data show that bindweed may be successfully eradicated by one and one-half to two years of intensive cultivation.

The prime requisite of any implement used for eradicating bindweed by clean tillage is that it shall cut off all the plants underground. The best implements for cultivating are the duckfoot and blade type weeders. Duckfoot sweeps should overlap at least three inches, while with blades it should be five or six inches. The most common depth of cultivation is about four inches, however variations in depth have little influence on eradication. Best results were obtained when the bindweed was permitted to grow about eight days after each emergence. When this was done only fifteen cultivations were required to eradicate the bindweed.

Smother crops alone can rarely, if ever, be depended upon to eradicate bindweed, but when used in combination with clean cultivation have proved successful.

THE CONTRIBUTION OF RESEARCH IN BARLEY TO AGRICULTURAL PROGRESS

By Ogden C. Riddle, Univ. of Nebraska

BARLEY is grown principally in the Northern and Western states, but is becoming of increasing importance in southern United States and Canada. Production over this vast area has increased regional and local problems of production in number and complexity.

High yield is of primary importance, but may be difficult to obtain due to such adverse factors as drouth, cold, disease, insect damage or lodging. The importance of yield may be tempered somewhat by specific quality requirements for various uses. The job of the barley research worker has been, and is, to produce a barley that will give maximum yields of grain having the attributes of quality necessary for the use to which the barley of the region is to be put.

Production trends of the past few years indicate a normal production of 300,000,000 bushels as compared to 15,500,000 bushels in 1860. Since 1866, corn acreage has increased threefold, oats five fold, and barley acreage is thirteen times greater. This increase reflects the favorable regard of agriculture and industry for the crop and its products. Efforts by research workers to improve the quality

and yield of the crop have resulted in a product of greater utility for numerous manufacturing processes and a successful competitor with other crops as an economical feed producer.

About seventy per cent of the nations barley crop is used as feed. The most important single variety used for this prupose is Trebi. Trebi resulted from an individual plant selection. It was released to farmers in 1918 and grown on 2,224,000 acres in 1935.

The thirty per cent which is used for malting and its many subsequent products is produced largely in the upper Mississippi Valley region and California. Manchuria and Oderbrucker were first grown as the standard malting varieties in the upper Mississippi Valley region. From these two varieties, by breeding and selection, have been developed new varieties with added desirable characters such as smooth awns and added disease resistance. Velvet, Wisconsin Pedigree 38, Glabron, and Minnesota 184 are four such varieties which, in general, combine greater ease of handling with more assurance of a uniformly good malting barley than either Manchuria or Oderbrucker.

In California, the outstanding malting barley is Atlas, which originated as a selection from Coast in 1924. It excels Coast in being earlier, more lodge resistant, and higher yielding.

Improved winter varieties, such as Missouri Early Beardless, are increasing the acreage in the South for the production of grain, and as winter pasture and winter cover.

Disease control as a factor in higher yield and quality is being effected by chemical means and the production of resistant varieties.

Coordinated effort among producers and consumers, and the research workers in both fields, is leading to the development of standardizations of type and quality that will further increase the usefulness of the grain.

CORN HYBRIDS

IN LAST year's report your committee indicated that steps were being taken to organize a Corn Improvement Conference. This organization was perfected at the meeting of the Society in Chicago in December 1937 and includes the research and extension workers of the state agricultural experiment stations and the U. S. Dept. of Agriculture interested in corn improvement.

Last summer the directors of the Corn Belt experiment stations called a meeting of this conference at Madison, Wisconsin, on September 16 and 17. Action was taken at that time on a number of problems that have arisen in connection with the hybrid corn programs.

The organization of the Corn Improvement Conference has provided opportunity for concerted action by the group interested in hybrid corn. This committee, therefore, has had no occasion for any action during the past year and this is likely to be the situation in the future. It is suggested, therefore, that this committee be discontinued.

H. D. Hughes G. H. Stringfield
T. A. Kiesselbach M. T. Jenkins, *Chairman*

FERTILIZERS

Subcommittee on Fertilizer Application.—The Subcommittee on Fertilizer Application has continued its participation in the program of the National Joint Committee on Fertilizer Application. Fertilizer placement experiments sponsored

by this committee in 1938 numbered 144, included 26 different crops, 66 locations and 27 states. Although this program has been underway for 10 years, the variety and scope of the work has continued to expand each year. Plans for the future include additional placement studies on tree fruits and strawberries, the extension of placement studies to crops grown under irrigation, the development of more adequate machinery for experimental purposes, and investigations designed to clarify the fundamental principles affecting the relations of fertilizer placement to weather, soil conditions, root development and other factors.

R. M. SALTER, *Chairman*

Subcommittee on Fertilizer Ratios.—As a matter of expediency the fertilizer using territory was divided into three regions as follows; the southern states, the northeastern states, and the north central states.

In the northeastern states the agronomists and representatives of the industry are working toward the adoption of 12 ratios with a corresponding number of minimum grade fertilizers and six acceptable "high analysis" grades.

In 8 southern states a committee composed of representatives of the industry, the state commissioner of agriculture, and agronomists have agreed upon a list of grades which may be licensed for sale in the given state. No other grade may be licensed. This procedure has resulted in a material reduction in number of grades offered for sale. It is hoped other southern states will make an effort to reduce the number of grades recommended.

Agronomists of the north central states have agreed on 28 grades that will meet their requirements. Of these, 10 grades are recommended by 4 or more of the 8 states. No grade containing less than 10 units of plant food are recommended. Nineteen grades have been placed on the recommended list for Indiana, Ohio, and Michigan and fertilizer companies have voluntarily featured these grades in their advertising.

The cooperation of the fertilizer companies in forwarding the work of the committee is greatly appreciated.

C. E. MILLAR, *Chairman*

Subcommittee on Symptoms of Malnutrition in Plants.—The members of the Subcommittee on Symptoms of Malnutrition in Plants have carried on during the current year collecting suitable material for the proposed book illustrating distinctive symptoms on plants due to plant food deficiency. Two papers have been published by the chairman of the subcommittee. A review of the literature dealing with "Distinctive Plant Symptoms Caused by Deficiency of any one of the Chemical Elements Essential for Normal Development" was published in the *Botanical Review*. Technical Bulletin 612 of the U. S. Department of Agriculture entitled, "Symptoms on Field-Grown Tobacco Characteristic of the Deficient Supply of Each of Several Essential Chemical Elements" is just off the press. Other papers have been published by members of the subcommittee or are in the course of publication.

A day was devoted to a meeting of the subcommittee on October 13, 1938, at the Cosmos Club, Washington, D. C. Seven of the subcommittee members were present and one absent. Professor Salter and Mr. Smalley, Chairman and Secretary, respectively, of the committee on Fertilizers were in attendance. Mr. Callister of the Plant-Food Research Committee of the National Fertilizer Association was also present and discussed ways and means of publication. Considerable progress was indicated in the assembling of the material for the proposed book.

It was voted to prepare a preliminary draft by February 1, 1939, or as soon thereafter as possible of all available material. It was voted that all material to be included in the proposed publication be approved by directors of the agricultural experiment stations and bureau chiefs of the U. S. Department of Agriculture with which the various chapter authors are connected, or by directors of Agricultural Experiment Stations from areas with which the work is concerned if written by authors in commercial work.

An exhibit of available material is to be held in connection with meetings of the American Society of Agronomy, November 16–18, at the Mayflower Hotel, Washington, D. C.

It is recommended that the subcommittee be continued until the work assigned is completed.

J. E. McMurtrey, Jr., *Chairman*

Subcommittee on Fertilizer Reaction.—The principal work of the Subcommittee on Fertilizer Reaction during 1938 has related to the evaluation of the availability of different forms of magnesium when used in complete fertilizers. This work was undertaken because the A.O.A.C. is trying to develop a chemical method for evaluating "available magnesium" in fertilizers. The choice of a chemical method will, of course, depend upon the availability to the crop of different sources of magnesium.

The subcommittee outlined a greenhouse and laboratory experiment that was designed to give data on the relative availability of magnesia in magnesium sulfate, hydrated dolomitic lime, selectively calcined dolomite, and different screen sized and sources of dolomitic limestone. Arrangements were made for the experiment to be conducted with five soils at the North Carolina Agricultural Experiment Station and with three soils by the Division of Soil Fertility, United States Department of Agriculture. The experiments are still in progress. The results from the first crop and set of soil samples were reported to the A.O.A.C. on November 14th by Doctors Dawson and Collins of the U. S. Department of Agriculture and the North Carolina Agricultural Experiment Station respectively.

Investigations similar to the above were conducted by Dr. J. B. Smith of the Rhode Island Agricultural Experiment Station. His data were also reported to the A.O.A.C. in a paper he presented as Associate Referee on Magnesium and Manganese in fertilizer.

Numerous field experiments relating to the relative efficiency of neutral and acid-forming fertilizers are being conducted in different states. The subcommittee, however, has made no special effort to initiate such experiments in the past year.

The past work of the committee is reflected in part in the greatly increased use of liming materials in fertilizers and the resultant decrease in the average equivalent acidity of American fertilizers. This has been shown by Mr. A. L. Mehring, U. S. Department of Agriculture, in a paper "Physiological Acidity of Commercial Mixed Fertilizers, 1929–1936". The tonnage of liming materials, mostly dolomitic limestone, used in the manufacture of fertilizers increased from 33,954 in 1929 to 98,654 in 1933 and 302,571 in 1936. The net equivalent acidity of American fertilizers decreased from 152 pounds calcium carbonate equivalent in 1933 to 19 pounds in 1936.

F. W. Parker, *Chairman*

Subcommittee on Soil Testing.—Important features of work under way are:

(1) Soils for Check Determinations by Soil Testing Methods. It is expected that by the spring of 1939 about 16 soils will be available for distribution, with representative samples of various types and fertility levels from the southern, middle-Atlantic, northeastern and corn belt sections.

(2) Soil Testing by the Fertilizer Industry. A survey has been made, through the cooperation of the National Fertilizer Association. Sixty-four companies are doing soil testing work. A large majority of the companies feel that soil testing should be done by the official agencies in the states, rather than by the commercial concerns.

(3) Reports of Expansion in Soil Testing by Official Agencies. Several additional states (at least four) have taken up soil testing, and others are investigating methods with a view to offering this service if a satisfactory method is available for their conditions. Fertilizer control receipts are being used to finance the work in some states, and the interpretation of tests by control chemists may present a problem.

(4) Reports of Development in Methods. No important new developments in the main features of the various methods have come to our attention. Several promising refinements in technique have been worked out. Methods for minor elements (boron, zinc and copper) are still definitely in the preliminary stages of development.

Plans are suggested for a group of papers dealing with correlations of fertility levels, as shown by the various methods, with respect to crop adjustments on different soil types, to be presented at the A.S.A. meeting next year.

M. F. Morgan, *Chairman*

WAYS AND MEANS OF INCREASING THE USE OF LIMESTONE IN THE SOIL CONSERVATION PROGRAM

THE following is an abstract of recommendations of a special committee of extension agronomists:

The Problem.—It is generally recognized that the extent to which a sound soil conservation and improvement program can be developed for the rotated and pasture land of the northeastern and north central states is limited chiefly by the speed with which we can get our acid land limed. A large percentage of the soil in the states east of the Great Plains is already acid.

A sound and permanent program of soil conservation must be built on the use of certain effective erosion-control and soil-building legumes, and it is a well-known fact that these legumes cannot be grown successfully on land of a certain degree of acidity. In order to bring back the productivity of both level and rolling land and to check erosion, good crops of legumes, such as sweet clover, red clover or alfalfa, must be grown either in rotation or in pastures and meadows.

Any attempt to side-step the liming of acid land in a long-time improvement program by promoting the growing of acid-tolerant legumes and grasses as soil-improving and soil-conserving crops is doomed to failure. The continued use of these crops to the exclusion of our more desirable soil-building legumes will only make a bad situation worse. The meager growth of these crops on strongly acid land will not materially build up the organic matter and nitrogen content of the soil nor will it furnish feed efficiently. As a matter of fact, the continued growing of these crops under strongly acid conditions means continued soil deterioration.

It should be kept in mind that this acid land will eventually have to be limed if it is to continue to be farmed. The longer liming is delayed, the more difficult it will be to finance the liming program from a decreasing income from the land.

The responsibility for the liming of these acid soils does not rest entirely on the farmer or land owner, but it is and should be of as much concern to the urban population as to the farmers. Plans for the solution of the problem must include the farms operated by the average or below average farmer as well as the farms operated by good farmers. The task is so big that concerted action by local, state and federal agencies is necessary and the educational agencies alone cannot accomplish the desired result.

Need for Liming.—While the U. S. Dept. of Agriculture and the colleges of Agriculture have, thru their extension services, stressed the need for limestone for the past 15 to 25 years, progress has been discouragingly slow. Agronomists of several states have prepared estimates of the lime needs of their states. Ohio needs two million tons of lime each year for the next 25 years in order to prepare Ohio farm land for growing satisfactory crops of clover and alfalfa. Fifty million tons are needed in Iowa. New York needs one million tons annually on the crop land to maintain the present lime content of the soil. An inventory of the lime requirements of Illinois farm land indicates a total need of approximately 50 million tons, while an average annual application of 2 million tons would be required simply to replace the lime lost each year through crop removal and leaching.

Credit for Purchasing Liming Materials.—The low productivity of much land, coupled with the drouth and low prices for farm products, during recent years, has made it impossible for many farmers to finance any extensive liming program without some assistance. At present there are no adequate local, state, or federal agencies from which the farmer can borrow for the purchase of limestone. The liming of acid soils will increase the soundness of the loans and greatly increase the possibility of prompt payments.

Production Credit Loans.—Loans from the Production Credit Corporation for the purchase of liming materials must now be repaid in one year, while substantial cash returns on an investment in liming materials may not be realized before the third or fourth crop after their application. Such loans should extend over a period of three to five years. We suggest that the Production Credit Corporation develop a plan for five-year loans to farmers for the purchase of liming materials.

In many cases a Commissioners loan would offer a more workable source of credit than the Production Credit loans. They would not be practical where the mortgage is held by an agency other than the Federal Land Bank because of the high costs of the appraisal and other costs. When the Federal Land Bank has the mortgage, the secretary of the local Loan Association could make the inspection for a small charge. Even when the farm already carries a Commissioners Loan a supplementary loan for liming materials might be made, if the borrower's past performance has been satisfactory. Commissioners loans may now carry money for the repair of buildings and this is a precedent for the practice of making such loans for the purchase of liming materials.

Federal Land Bank Loans.—When new Federal Land Bank loans are made on farms which need lime, the liming of the land might well be a requirement of the loan. The loan could be increased to care for the expense or a second short time loan might be drawn up to care for this purpose. Credit for liming the land should be extended in the case of farms on which the Federal Land Bank now holds mortgages. Other loaning agencies might well adopt these policies.

Other Sources of Credit.—Many farmers will not be able to borrow from any branch of the Farm Credit Administration or other credit agencies because of lack of collateral for loans. To meet this situation state legislation authorizing the County Commissioners or County Board of Supervisors to issue bonds to finance liming programs for such farms would help meet the situation. Money received from the sale of the bonds would be loaned to farmers who have no other source of credit. These loans might run for five years and be paid in five annual installments with the taxes on the farms.

Agricultural Conservation Program.—The soil-building practices under the Soil Conservation and Domestic Allotment Act have done much to encourage a sound soil conservation program. The limestone provision has offered farmers the needed financial assistance in this fundamental step in soil conservation.

Many farmers do not take advantage of the program to help lime their acid soils. Some purchased clover seed, to earn their soil building payments, and seeded it on land so acid or so deficient in phosphorus that it could not produce a satisfactory crop.

In order to encourage more effective soil-building programs, more encouragement should be offered for liming.

In order to accomplish this, the following proposals are offered:

1. The soil-building allowances should be increased materially.
2. Where new seedings of legumes are made as a soil building practice, evidence must be offered that the past treatment of the land has been such that the clover or alfalfa has a good chance of producing a satisfactory crop. Standards for these treatments would be prepared by the Agronomy Departments of the states concerned.
3. Encourage more farmers to use limestone as a means of earning soil-building payments by offering some special inducement. This might be done by offering cooperators in the program an opportunity to accept payment in limestone in lieu of check.

The Soil Conservation Service.—The Soil Conservation Service appreciates the value of liming materials in a soil conservation program and its efforts have increased their use in communities where it has worked. It is hoped that the Soil Conservation Service may be able to devise means to further increase the use of liming materials.

J. H. BARRON   EARL JONES
J. L. BOATMAN   C. M. LINSLEY, *Chairman*

RESOLUTIONS

IN MEMORIUM

THE Committee on Resolutions announces with regret and with a feeling of great loss, not only to the Society but also to their respective families, the deaths of s x agronomists during the past year.

These are Thomas Lyttleton Lyon, Cornell University, Ithaca, N. Y.; Alfred Evan Aldous, Kansas State College, Manhattan, Kansas; John Budd Wentz, Iowa State College, Ames, Iowa; Herman Hamilton Wedgworth, Everglades Experiment Station, Belle Glade, Florida; Robert Mar'in Barnette, University of Florida, Gainesville, Florida; and Frederick William Oldenburg, University of Maryland, College Park, Maryland.

ALFRED EVAN ALDOUS

DR. ALFRED EVAN ALDOUS, Professor of Pasture Improvement, Department of Agronomy, Kansas State College, died at his home in Manhattan, Kansas on May 4. He is survived by his wife, Mrs. Coral K. Aldous, and two daughters, Lois Geraldine and Joan.

Dr. Aldous was born near Ogden, Utah on November 18, 1885. In 1916 he married Coral Kerr.

Dr. Aldous was graduated from the Utah Agricultural College in 1910 and entered the U. S. Forest Service immediately upon graduation. In 1911 he took special graduate work in botany and plant ecology at the University of Minnesota. In 1934 he was granted the Ph.D. degree from the University of Nebraska. Previous to coming to Manhattan to assume the direction of the pasture research program in 1926, Dr. Aldous was with the Land Classification Division of the U. S. Geological Survey, and previous to that time had been in range and grazing research with the U. S. Forest Service.

Dr. Aldous made many contributions to our knowledge of pasture improvement, range management and research in the selection and development of pasture grasses. The results of his experimental work have been published in several experiment station bulletins and technical journals. He was outstanding in his profession as a teacher, investigator and leader, and will be greatly missed professionally, not only by Kansas but by his many friends throughout the country.

Dr. Aldous was a member of the American Society of Agronomy, and has served on several committees of the Society. He was also a member of the American Association for the Advancement of Science Sigma Xi, Phi Kappa Phi, Alpha Zeta, and Gamma Sigma Delta.—R. I. THROCKMORTON.

ROBERT MARLIN BARNETTE

DOCTOR ROBERT MARLIN BARNETTE, Chemist at the Agricultural Experiment Station of the University of Florida, was killed instantly on the evening of October 31 while driving alone in his car a few miles north of Gainesville. In the immediate family of his parents Dr. Barnette is survived by three sisters and a brother, all living in South Carolina at the present time. Dr. Barnette was born in Rock Hill, County of York, South Carolina, November 30, 1900. In 1920 he graduated from Clemson College and in 1923 received the Ph.D. degree from the University of New Jersey where he specialized in soil chemistry.

Following his graduation from the New Jersey institution, Dr. Barnette spent a year abroad in travel and study. His study was divided equally between the Rikkslandbouwproefstation in Gröningen, Holland, where he studied under Dr. D. J. Hissink and at the Eidgenossische Technische Hochschule, in Zurich, Switzerland, where he spent much of his time in the laboratories of the late Professor George Wiegner.

Following his return to the United States, Dr. Barnette worked for two years as Assistant Chemist at the Tennessee Agricultural Experiment Station. In 1925 he was appointed Assistant Chemist at the Florida Agricultural Experiment Station, became Associate Chemist in 1929 and Chemist in 1932. At the time of his death he was in charge of the Land Use Division of the Department of Chemistry and Soils.

As indicated by his published works, Dr. Barnette has largely interested himself in the fundamental nutrition of plants especially as influenced by the physical characteristics of the soil environment in which they grow. Having studied with

Wiegner and Hissink in Europe just at the time base exchange phenomena in the soil were beginning to be understood and their importance appreciated, Dr. Barnette became a pioneer worker in this field in Florida and in the Southeast. Throughout his work both organic and inorganic colloids were emphasized and the importance of the rôle of organic matter in the soil in this and other connections repeatedly pointed out.

In the death of Dr. Barnette the American Society of Agronomy and the Soil Science Society of America have lost a keenly discerning and energetic worker. To all who have had personal associations with him and especially to those of us who have been privileged to live and work closely with him there can not but come a deep feeling of loss in the passing of a staunch and ever sympathetic friend.—R. V. ALLISON.

THOMAS LYTTLETON LYON

THE death of Thomas Lyttleton Lyon removed not only one of the founders of the American Society of Agronomy but also the man, who, as much as any other, was responsible for its inception. From the year of its establishment in 1907 until his retirement as head of the Department of Agronomy at Cornell University, he worked earnestly for the success of the Society. Its growing membership and its expanding publications are evidence of the foresight of the men, who in those early days dared with him to launch such a project. Not only was Dr. Lyon president of the Society but for several years he served as its secretary. Later, as an especial evidence of esteem, he was made historian and there is recorded in the January, 1933, number of this JOURNAL a brief history of the Society from his pen.

Dr. Lyon's scientific attainments are so well known that only brief mention of these need be made here. His lysimeter studies, his work on the various phases of soil nitrogen, his rotation and fertilizer experiments and his cereal investigations are outstanding. His published scientific articles are many. His textbooks are noteworthy; the first, "Principles of Soil Management" (with E. O. Fippin), was published in 1908 and his sixth, "The Nature and Properties of Soils", 3rd edition (with H. O. Buckman), appeared in 1937, a few months before his retirement from active duty. His career was a long and busy one.

Thomas Lyttleton Lyon was born in Allegheny County, Pennsylvania on Feb. 17, 1869. His passing occurred on October 7, 1938 at his home in Ithaca, New York where he had resided for thirty-two years. Dr. Lyon prepared for college in the Pittsburgh High School and graduated from Cornell University in 1891. Later he studied with Prof. Tollens at the University of Goettingten and with Prof. Caldwell at Cornell University. He received his Ph.D. degree from the latter institution in 1904.

In 1891 young Lyon accepted a position at the University of Nebraska and served there as instructor in chemistry, assistant chemist and finally as professor of Agriculture until 1906. From 1899 to that date he was also associate director of the Nebraska Agricultural Experiment Station. While in Nebraska he was married to Bertha L. Clark of Lincoln. Two sons added much to the happiness of his married life. In 1906 Dr. Lyon was called to Cornell University by Dean Liberty Hyde Bailey as Professor of Experimental Agronomy and was made head of the Department of Soil Technology in 1912. This was later expanded into a department of agronomy.

Although Dr. Lyon made several notable scientific contributions while at the University of Nebraska, his most valuable work was done at Cornell University.

Caldwell Field, named in honor of his old teacher, Prof. George Chapman Caldwell, was the site of his lysimeter and plat experimentations and other field studies. It was for years the mecca of those interested in such types of investigation. Nothing pleased him more, when health and time permitted, than a trip to "the field", as it was called, with visitors or other friends. Because of his amiable disposition and broad cultural background, Dr. Lyon was an ideal host, genial and delightfully conversant with almost any subject his guests might chance to broach. Many still remember him as he was in those more vigorous days before his waning health began to curtail his outside activities.

Although it is often difficult for colleagues to correctly evaluate the work and influence of their associates, agronomists the country over will agree that the passing of Thomas Lyttleton Lyon was a real loss to scientific agriculture and to soil science especially. His good judgment, his quiet dignified efficiency, his considerate companionship, his high ideals and the soundness of his scientific research mark a man whom it was good to know.—H. O. BUCKMAN.

FREDERICK WILLIAM OLDENBURG

A SEVERE loss was sustained by the Extension Service, by his associates, and by the farmers of Maryland in the passing of Frederick William Oldenburg, who for the last 20 years had been specialist in agronomy. Mr. Oldenburg's death occurred at his home in Hyattsville on January 22, following an automobile accident on November 28, 1937.

His earnest devotion to his work, his untiring efforts, his genial personality, and unfailing loyalty had won for him a place in the hearts of those with whom he came in contact. He was widely known throughout the state and deserves a large share of credit for many important developments in Maryland agriculture. Mr. Oldenburg devoted much of his time in extension work in encouraging farmers to use adapted varieties of seed and to improve the quality of their seed. Several years prior to his death he developed a program, in cooperation with the Soils Department, of giving farmers assistance in their fertility problems by providing facilities for making quick tests and in interpreting the results for them.

His work in extension contributed much in bringing about the increased average yields per acre of field corn and wheat in Maryland over the past decade.

Mr. Oldenburg was born in Wisconsin on December 30, 1873. He was a member of the class of 1899 at the United States Military Academy. In 1902, he graduated from the Oshkosh Normal School at Oshkosh, Wisconsin. He became a teacher and superintendent of schools in various Wisconsin cities and later a member of the faculty at the Iowa State Teachers' College after receiving a degree from the University of Wisconsin in 1915. He was president of the Normal School at Park River, North Dakota, before coming to the University of Maryland in 1917.

Mr. Oldenburg was a member of the Association of Graduates of the United States Military Academy, the Knights of Pythias, and Tau Chapter of Episilon Sigma Phi fraternity. He was secretary of the Maryland Crop Improvement Association, a member of the American Society of Agronomy, Maryland Farm Bureau, and the Hyattsville Horticultural Society.

Surviving Mr. Oldenburg are his wife and three children, Mrs. Waverly W. Webb and Mrs. Dayton Watkins of Hyattsville and Lester Oldenburg of Hyattsville, Maryland. Interment was in Arlington National Cemetery.—JOHN W. MAGRUDER.

Herman Hamilton Wedgworth

HERMAN Hamilton Wedgworth of Belle Glade, Florida, a member of the American Society of Agronomy, died during the evening of October 12, a few hours following severe injuries sustained while supervising construction operations on one of his many agricultural projects in the Everglades area. In his immediate family he is survived by his wife, Ruth Springer Wedgworth, a son and two daughters.

Mr. Wedgworth was born in Mississippi in 1901, received a bachelor's degree from Mississippi Agricultural and Mechanical College and a master's degree from Michigan State College in his chosen field of plant pathology. He served on the Mississippi Plant Board as Inspector, was Instructor in the Department of Plant Pathology at Cornell for two years, was Associate Plant Pathologist on the Mississippi State Plant Board for two years, was Research Assistant in plant pathology at Michigan State College from 1928 to 1930, and in 1936 was appointed Associate Plant Pathologist at the University of Florida and stationed at its Everglades Experiment Station near Belle Glade.

Although a pathologist by training, Mr. Wedgworth quickly developed a thorough appreciation of the important relationship between soil conditions and the normal growth of plants, especially with regard to their resistance to disease. It was in this field that he made his most important contributions while working at the Everglades Experiment Station.

After two and one-half years of faithful and effective work with the State in the Everglades, he left the public service to engage actively in the fascinating agriculture of that great region. Keen of mind and untiring in his work, in five years he rapidly built up a highly diverse project involving more than a thousand acres under cultivation—largely to diverse truck crops, extensive warehouse and packing facilities, cold storage, fertilizer manufacture and others.

In the death of Mr. Wedgworth the Societies with which he had recently become affiliated have lost a member who had passed through a productive period of research in soil and plant science and taken his broad experience and understanding into the field of practical production on a broad scale. The pioneering community in which he worked recognized him as an agricultural and civic leader and will feel the loss in still other ways for many years to come.

During the entire three and one half hours he lived following the accident which crushed and paralyzed his body on one side, his mind was active and the entire time was given to counsel and planning for the future with his wife who was so soon to assume the heavy responsibility for his life work, their extensive farming project and their children. He recognized clearly the approach of death itself and told those at his bedside of that approach.—R. V. Allison.

John Budd Wentz

IN THE passing of Doctor Wentz we who had served with him through a period of years lost a friend whom we had all come increasingly to respect and admire, because of his earnest, sincere, friendly attitude, and his high personal standards of conduct. We have not known a man of whose integrity of character we were more certain—who set high standards for himself and who was willing to give much of himself that others might gain in the most worthwhile endeavors in life. We who were closest to him and knew him best have profited most—our lives have been enriched by our knowledge of him in his daily life of duties well done.

In the passing of Doctor Wentz, Iowa State College lost the services of a man who was respected and admired for his personal accomplishments, both within the college and without, a teacher, and an investigator who was a searcher for the truth. In addition to his regular duties he served faithfully and continuously on important college committees.

Doctor John Budd Wentz passed away on August 24, 1938, at his home, 1023 Brookridge Avenue, Ames, Iowa. He had been ill for several months but continued his work at the college with his usual interest and zeal just as long as he was physically able to do so.

Doctor Wentz was 47 years of age, having been born in Chariton, Iowa, March 4, 1891. He had his undergraduate college training at the North Dakota State College making his home with his uncle, President J. H. Shepperd. He taught agriculture and biology at the South Dakota State Normal School, Spearfish, South Dakota, in 1913–14 and the next year was employed by the U. S. Dept. of Agriculture, before going to Cornell University as a graduate assistant in the fall of 1915. He was granted the master's degree by Cornell in 1916 and the Ph.D. degree in 1928.

He was on the staff of the Maryland State College as professor of agronomy from 1916 to 1921, when he joined the staff of Iowa State College with the rank of associate professor. Doctor Wentz' particular interest during the 17 years that he served on the college staff here was in the field of crop breeding, teaching this subject and directing the research of graduate students in this field. He will be remembered with affection by the large number of graduate students who came under his guidance and to whom he rendered great service. He also was active on genetic research problems with field crops, contributing a large number of research papers reporting his work.

Doctor Wentz was a member of the American Society of Agronomy, the Genetics Association, Association for the Advancement of Science, and the Iowa Academy of Science. In recognition of his productive research Doctor Wentz had been elected to the following honorary societies: Sigma Xi, Alpha Zeta, Phi Kappa Phi, and Gamma Sigma Delta.

Doctor Wentz contributed greatly to the community in which he had made his home. He has always been very active in the Congregational Church, giving long years of service in various official capacities. He also has contributed greatly to the development of better citizens in the future through the Boy Scouts organization and through the Parent-Teacher Association.

Dr. Wentz was united in marriage to Hazel Edna Patterson September 22, 1915, at Spearfish, South Dakota. He is survived by his wife and one son, John Budd, Jr., who is a sophomore in Iowa State College.—F. D. KEIM.

UNADAPTED AND NON-DESCRIPT SEEDS

THE American Society of Agronomy views with concern the present promiscuous interstate shipping of unadapted and non-descript seeds, which often are of unknown variety and may be foul with weed seeds and seed-borne disease organisms. The Society is mindful of the efforts now being made by state and federal seed law enforcement agencies to curb such movements, but also realizes that present laws are inadequate to cope with the situation. Therefore, be it resolved

That the Society urge that appropriate steps be taken toward the enactment of adequate seed laws, both state and federal, and that when adequate seed laws are in the statutes that they be fully enforced so as to eliminate such traffic.

Be it further resolved that members of this Society do all in their power to support and cooperate with those now endeavoring to regulate or control the sale of seeds so that the purchaser will obtain only those stocks of seeds which are adapted to his locality.

Also be it resolved that a copy of these resolutions be presented to the Secretary of Agriculture of the United States and to each appropriate seed enforcement official within the separate states, as representing the firm conviction of members of this Society who are charged with the improvenemt and safeguarding of American field crop agriculture through its supplies of seed.

RESEARCH AND EXTENSION IN WEED ERADICATION AND CONTROL

Whereas the weed menace constitutes an enormous tax upon the agriculture of this country and the area infested with noxious weeds in the United States has been approximately doubled every five years, despite all past efforts of control and eradication,

Therefore, be it resolved, that the American Society of Agronomy in conference, assembled in the city of Washington, November 16, 1938, urgently recommend that the Secretary of the United States Department of Agriculture give consideration to the desirability of meeting this menace thru a program of research and extension in order to develop more adequately methods and means for combating noxious weeds.

O. S. Aamodt
M. F. Miller
R. I. Throckmorton
J. D. Luckett, *ex-officio*
F. D. Keim, *Chairman*

NOMINATING COMMITTEE

Professor A. T. Wiancko presented the report of the Nominating Committee and upon motion the Secretary was instructed to cast a unanimous ballot for Dr. F. J. Alway for Vice-President. Dr. Ralph J. Garber and Dr. F. B. Smith were elected representatives of the Society on the Council of the American Association for the Advancement of Science. Dr. Ralph J. Garber automatically succeeded to the Presidency and Dr. William A. Albrecht automatically succeeded to the Chairmanship of the Soils Section. Dr. F. D. Keim was elected to the Chairmanship of the Crops Section.

Meeting adjourned.

F. B. Smith, *Secretary*

AGRONOMIC AFFAIRS

MINUTES OF THE CROPS SECTION BUSINESS MEETING, WASHINGTON, D. C., NOVEMBER 17, 1938

A RESOLUTION on the dissemination of unadapted and nondescript seed stocks and a resolution on weed eradication and control were presented by Professor F. D. Keim and, after discussion, were unanimously adopted and referred to the Committee on Resolutions of the Society. (See pages 1071 to 1072.)

The Nominating Committee appointed by Dr. Ide P. Trotter, Chairman of the Crops Section, and comprising H. B. Sprague, *Chairman*, H. H. Laude, and H. C. Rather, presented the following slate of officers for the Section for 1939 which was unanimously adopted: Professor F. D. Keim, *Chairman*, and Dr. H. H. Love and Professor O. W. Dynes, members of the Executive Committee.

The session closed with a showing by Professor Keim of motion pictures of the Fourth Grassland Congress.

OFFICERS OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1939

President, RALPH J. GARBER, U. S. Dept. of Agriculture.
Vice-President, F. J. ALWAY, University of Minnesota.
Chairman, *Crops Section*, F. D. KEIM, University of Nebraska.
Chairman, *Soils Section and President of the Soil Science Society of America*, WILLIAM A. ALBRECHT, University of Missouri.
Editor, J. D. LUCKETT, New York Agricultural Experiment Station.
Secretary-Treasurer, G. G. POHLMAN, Agricultural Experiment Station, Morgantown, West Virginia.
Members of the Executive Committee, ex-officio, EMIL TRUOG, University of Wisconsin, and F. D. RICHEY, Ashville, Ohio.

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1939

President, WM. A. ALBRECHT, Columbia, Missouri.
Past President, A. M. O'NEAL, Washington, D. C.
Secretary, W. H. PIERRE, Ames, Iowa.
Treasurer, G. G. POHLMAN, Morgantown, W. Va.
Editor, J. D. LUCKETT, Geneva, New York.

Section I

Chairman, G. B. BODMAN, Berkeley, California
Past Chairman, L. A. RICHARDS, Ames, Iowa
Secretary, J. F. LUTZ, Raleigh, North Carolina

Section II

Chairman, J. W. TIDMORE, Auburn, Alabama
Past Chairman, E. E. DETURK, Urbana, Illinois
Secretary, M. S. ANDERSON, U.S.D.A., Washington, D. C.

Section III

Chairman, A. W. Hofer, Geneva, New York
Past Chairman, N. R. Smith, U. S. D. A., Washington, D. C.
Secretary, O. H. Sears, Urbana, Illinois

Section IV

Chairman, J. J. Skinner, U. S. D. A., Washington, D. C.
Past Chairman, H. J. Harper, Stillwater, Oklahoma
Secretary, W. H. Metzger, Manhattan, Kansas.

Section V

Chairman, S. S. Obenshain, Blacksburg, Virginia
Past Chairman, W. E. Hearn, U. S. D. A., Washington, D. C.
Secretary, T. M. Bushnell, Lafayette, Indiana

Section VI

Chairman, W. L. Powers, Corvallis, Oregon
Past Chairman, E. A. Norton, U. S. D. A., Washington, D. C.
Secretary, H. E. Middleton, U. S. D. A., Washington, D. C.

DOCTOR SMITH RESIGNS

IT WAS with deep regret that the Executive Committee accepted the resignation of Dr. F. B. Smith as Secretary-Treasurer of the American Society of Agronomy, effective with the close of the annual meeting in Washington. Pressure of duties in his still comparatively new surroundings at the University of Florida seemed to make it imperative even a year ago that he be relieved of the heavy duties of the Secretary's office. He agreed to see the Society through the past year, however, with the many necessary readjustments that had to be made following the death of Doctor Brown, but again asked to be relieved of his duties with the close of this year's business.

It is common knowledge that Doctor Smith has met exceedingly well all of the varied demands made upon him and the affairs both of the American Society of Agronomy and of the Soil Science Society of America have prospered under his direction. Fortunately, his experience and counsel will still be available to the Society and to his successor.

On behalf of the new Secretary-Treasurer, Dr. G. G. Pohlman, Head of the Department of Agronomy, West Virginia Agricultural Experiment Station, Morgantown, West Virginia, we bespeak the indulgence of all members of the Society while he familiarizes himself with the details of his duties. So much depends upon the efficiency of the Secretary's office in the smooth operation of the affairs of the Society that one is inclined to take many things for granted that actually represent hours of labor and careful attention to infinite detail. The Society is fortunate indeed that a man of Doctor Pohlman's demonstrated efficiency and leadership is willing to assume the obligations and responsibilities of this new office in which the only reward can be the satisfaction of doing a very necessary job in a workmanlike manner.

PRELIMINARY NOTICE CONCERNING THE FOURTH INTERNATIONAL CONGRESS OF SOIL SCIENCE

ATTENTION is hereby called to the fact that the time for the call for papers by the general committees of the International Society of Soil Science for the 1940 meeting of the Society is approaching. The American members of the International Society of Soil Science should give prompt consideration to the submission of titles and abstracts of their anticipated papers to the appropriate section representatives as listed below.

Section I.
Soil Physics—L. D. Baver, Ohio State University, Columbus, O.

Section II.
Soil Chemistry—C. E. Marshall, University of Missouri, Columbia, Mo.

Section III.
Soil Microbiology—Charles Thom, Bureau of Plant Industry, Washington, D. C.

Section IV.
Soil Fertility—W. H. Pierre, Iowa State College, Ames, Iowa

Section V.
Soil Morphology—L. C. Wheeting, State College of Washington, Pullman, Washington

Section VI.
Soil Technology—A. G. McCall, Soil Conservation Service, Washington, D. C.

Any suggestions for symposium subjects should be sent to the general chairman.—W. P. Kelley, *General Chairman*, Agricultural Experiment Station, Berkeley, California.

SUMMER MEETING OF CORN BELT SECTION

THE Corn Belt Section of the American Society of Agronomy will hold its annual summer meeting in Ohio on June 14, 15, and 16, 1939. Tentative plans include an inspection and discussion of the work at Wooster, Columbus, and several of the outlying experiment farms. An invitation has been extended to the Northeastern and Canadian agronomists to meet with the Corn Belt group at that time.

NEWS ITEM

Doctor A. J. Pieters, Principal Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, retired November 30.

Doctor Pieters will be associated with the Greens Section of the U. S. Golf Association, with headquarters in Washington, and will engage in the development of fine turf grasses.

INDEX